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ON THE IGNEOUS AND PYROCLASTIC ROCKS OF THE BERWYN HILLS (North Wales).

By the Late THOMAS HENRY COPE, F.G.S.

(Edited by CHARLES B. TRAVIS).

LIVERPOOL:
C. Tinling & Co., Ltd., Printing Contractors, 53, Victoria Street.

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Note by the Editor.—Mr. T. H. Cope, F.G.S., commenced his investigations into the igneous geology of the Berwyn Hills about the year 1898. At the outset it would appear that the late Joseph Lomas, F.G.S. collaborated with him to some extent, and a short paper, embodying some results of their observations, entitled "On the Igneous Rocks of the Berwyns," was read before the British Association meeting in 1903. For several years, however, both before and after the death of Mr. Lomas, it is clear that Mr. Cope carried on the work alone, and in connection therewith he stated that he had examined almost every outcrop of igneous and fragmental rock in the area. He had quite finished the field-work, and the manuscript of this paper was in a fairly advanced state of preparation when his untimely death took place in 1913. The investigations, extending over so many years in the leisure time of a busy commercial life, had been conducted with such characteristic thoroughness, and had thereby involved such a great amount of work, that it was felt by his geological friends that it would be a great pity if his labours were to be in vain. As the result of arrangements made by the Council of the Liverpool Geological Society (of which Mr. Cope had been a member for many years) his widow very willingly transferred his MS. field-notes and specimens to the writer, to whom was entrusted the task of editing and completing the manuscript, and the paper, which is now published under the auspices of the Society, at the expense of Mrs. Cope, is intended to form a memorial to the late author.

In addition to the editorial duties, it was found necessary by the writer, in order to complete the paper, to furnish a petrological description of certain groups of rocks, left undescribed by Mr. Cope, from material already collected, as well as to write the concluding sections of the paper. His contributions are indicated by the initials appended to each section. In the work of editing it has been his constant endeavour to record the views of the late author, wherever expressed or implied in his notes, rather than his own opinions, and the editor's responsibility is confined to his own contributions. Had Mr. Cope lived a little longer to complete the paper himself, it is possible that he might have modified it in some of its details, but there can be no doubt, in view of the prolonged attention which he had devoted to the work, that this posthumous paper expresses his mature conclusions on the whole. —C. B. T.

I. Introduction.

The chain of the Berwyn Hills is well defined by the boundary line between the counties of Merioneth, Montgomery and Denbigh, which in this area follows their crests. This line forms also the main water-parting, and has an irregular North-east trend from a point 2 miles West of the head of Lake Vyrnwy to near Llangollen, a distance of 18 miles.

It is necessary for the purposes of this paper to embrace, not only the chain of hills, but also a tract of considerable size extending eastwards to the Carboniferous Limestone, giving a total area of about 150 square miles, for, while the highest elevations are mainly due to the presence of igneous rocks, these cannot be dissociated from either the continuous bedded volcanics on the North or the numerous isolated exposures scattered in various localities. The description of those rocks contained in a comparatively narrow tract round the border, then, would not suffice to bring the whole of the igneous rocks under review in what may be regarded as a self-contained area of later Bala vulcanicity, greatly denuded and admirably dissected.

This constitutes a large portion of the Central Upland of Wales, consisting principally of Ordovician sediments, flanked on three sides by formations of Silurian age which once entirely covered it.

It is not intended here to enter into the detailed history of the sedimentary rocks, which, nevertheless, is highly essential for the correct interpretation of numberless faults, as yet unmapped, and variations in horizontal equivalents. The task is the correlation of notes recorded during a series of years in a résumé of the nature and classification of the bedded and complementary hypabyssal igneous rocks of the region.

On entering upon the work in the Berwyn area with a sense of structural detail easily mastered, it soon became apparent that here was no task of simple revision or correction, with later knowledge, of conventional colouring, but rather a tangle of intricate problems to be solved which, indeed, must be the attributes of all domal structure.

It seems to me, therefore, that some description of the igneous rocks alone would suffice for the moment, pending that detailed palæontological work which is so much needed, for the difficulties to be overcome must be a factor of absorbing interest in this comparatively unknown, as yet unspoilt, corner of wild Wales.

II. Previous Literature.

A considerable amount of work has been done with reference to the acid lava rocks (rhyolites and felsites) of North Wales, and there is no apparent difficulty in bringing many of the series recorded into relation with groups lying at the base of the Berwyn sequence; but of their fragmental associates, viz.: the so-called volcanic "ashes," the tuffs, agglomerates and breccias, there are few records of detailed petrographical study.

Particularly is this true of the contemporaneous pyroclastic rocks of Bala age—least of all have those of the Bala-Berwyn country received the attention they so well deserve.

Of the Berwyns, as a whole, the literature is a sparse one, and, since Ramsay's classic memoir, work has been confined, at long intervals, to areas of small dimension.

Included in the most recent publication,* the paper by Messrs. Groom and Lake, of 1908, which deals entirely with the Glyn Ceiriog district, is found a carefully-compiled list of works dealing especially with this area, which it will be unnecessary to recapitulate here.

*"The Bala and Llandovery Rocks of Glyn Ceiriog (North Wales)."—Q.J.G.S., vol. lxiv., 1908.

Maps.

On the original Geological Survey Maps the area is shown in its most simple form. The igneous outcrops are outlined with as much precision as the scale allowed, and in only a few cases are boundaries drawn as "uncertain"; for these there is ample justification. Some exposures are not mapped, while, considering the great detail shown in the much-faulted Caradocian and Ashgillian country round Bala, it is curious that so little has been done with regard to the complementary network of faults on the Berwyn fold itself.

The horizontal sections are at variance with the solid maps. They bear the names of Jukes and Aveline, and in all is shown a far wider extension of Llandeilo shales than apparently exists.

The old series maps embracing the region are:— Qr. sheets LXXIV, S.E. and S.W.; and LX, N.W.; LXXIV, N.E. and N.W. The volcanic area is confined to the first three named.

Horizontal sections: Sheet 38, Section No. 1, Section No. 2, and Sheet 35.

III. General Structure of the Area.

The structure is essentially domal. The hills on the North, West, and South-west still form a ring on which the highest contour-line rarely drops below 1,000 feet; but the middle has been denuded, and the land slopes away to low levels on the South-east, where an extensive drainage system has deeply eroded it.

From the highest summits the country conveys the impression of a limitless expanse of unimportant rounded hills, under certain conditions suggesting a great eroded plain; it is, in fact, an ancient plateau, or peneplain, furrowed by deep valleys which shelter a drainage-system as yet far from mature. The salient features of the resultant hills are evidence of the topographical influence exerted by decaying remnants of the igneous rocks which characterised the period.

On the North and West margins the present hills dip under the geo-syncline forming the Silurian trough, where the Upper Bala beds plunge beneath the Llandovery series or members of the Tarannon, Denbighshire or Wenlock groups. This at one time applied to the South-west country, but on the crest of a great fold-wave local beds were reversed from a normal direction, thrown over through the vertical angle and as much as 10° in the opposite direction. This is well demonstrated on Broches-y-Foel Ortho and Das Eithin. As a result we find a rolling complex of crushed and tilted stratified beds extending over broken country from Garthbibio to Llan-y-blodwel.

On the South-east is a broken and shattered district, largely composed of fossiliferous sandstones of Bala age. Eastwards, on an area of greatly reduced altitude, the great scarp of the Carboniferous Limestone runs North from Llan-y-mynech to the Clwydian range, across the strike of the sedimentary beds and with strong unconformity.

On all sides the dip is seen to slope outwards from a main axis, becoming steeper as the area of central uplift is approached; thus, on the lower levels of the northern and western slopes the dip rises from an average of 17° to 34°; on higher ground, as near Llandrillo, in the Dee Valley, from about 40° to 58° in the lowest beds of all.

Near the district overlain by the Carboniferous Limestone dips are not so uniform, for, while on the North beds sloping down towards Llangollen rarely exceed 20°, the older formations brought up to the crown of the uplift show a series of small folds, where anticline dips into shallow syncline at angles from 4° to 65°.

In the South-west crush-area dip-angles and their direction vary incessantly over a short distance, and range from 22° to the vertical.

The action of an original pressure from the North-west had the effect of producing the simple monoclinal N.E.-S.W. ridge, perhaps with a tendency to over-folding. Such pressure was, in common with the other great movements known in Wales, Caledonian in direction.

But in order to give rise to the present structure it is necessary to postulate an easterly or secondary thrust, probably in Devonian times or later, to account for the strong deflection of the main axis.

Thus, with the idea of cross-folding in mind, the torsional movement arising from two such conflicting stresses resulted in the weakening of a central domal area and its subsequent susceptibility to denuding forces.

The agencies, which through long ages planed down the rising land, removed in turn not only the Silurian formation down to the Valentian series, but also an enormous thickness of the Ordovician sediments.

The ultimate result we find in a broken curved ridge or saddle, having a convex side to the North-west and a bent anticlinal axis of 26 miles: a well-dissected country in no way masked or confused by formations of any age between the Upper Llandeilo and the Ashgillian representatives of the highest Bala Beds.

Of the building and development of the country in Ordovician times a clear idea is obtainable, nor is it difficult to reconstruct the tale of intermittent volcanic activity, the results of which were spread over a far greater area than that outlined by existing exposures.

The upturned edges of the highest contemporaneous eruptive beds in forming a ring so nearly continuous are sufficient testimony to the extent of strata removed, also where dip-escarpments have been locally overwhelmed by thrusting their approximate horizons are fairly indicated.

Lastly, intrusive rocks, representing a more basic portion of a differentiated magma, are in their turn admirably exposed by the same processes of degradation for the study of their habit and relationship.

Rivers.

The drainage of the Berwyns is gathered into three main streams, the Dee, Ceiriog, and Tanat. The first-named, North-west of the water-parting, has as tributaries the torrents Afon Arddau, A. Trystion, A. Llynor and the Ceidiog river, which seam the marginal slopes to a considerable depth.

The Ceiriog, meeting the Dee at Ruabon, and the Tanat, both eastward flowing rivers, gather the water from the high ground East of the watershed. On the South, Afon Cedig into Vyrnwy Lake and the Rhaiadr, with the Iwrch, flowing into the Tanat, are responsible for the drainage of a large collecting-ground.

One stream only, the Morda, cuts the limestone escarpment in a gorge near Rhyd-y-Croesau.

Few of the deeply-worn beds of these streams but yield good natural sections, in many whole series are exposed, and in few is it not possible to locate at least one representative page in the volcanic history of the region.

The Glyn Valley has, it will be seen, been already described in detail. This rift in the outer walls is of exceptional interest in its aspect of outward simplicity of construction; indeed, so clearly is the geology presented to the observer that it may be said that this narrow valley holds the key of most of the Berwyn problems.

Faults.

With regard to faulting, the structure becomes more complicated; the broken country round Llangwm, with its great plexus of virgating faults, naturally suggests a complementary system of dislocation within the uplift area, and this is found to be the case.

A few major-faults are far reaching in their effects, and, when related to a highly intricate system of minor folding and fracture, have produced a complex of which detailed stratigraphical work is the only key.

Lesser faults, intimately connected with local igneous exposures, will be noted in place; meanwhile the principal of the main lines of weakness affecting the whole area may be noted.

The existence of the two great N.N.W. strike-faults, diverging from Carnedd-y-ci, traversing the entire region and ending in the Tanat Valley, there is no reason to doubt. These faults, heading respectively North-east and West, give a wedge-shaped mass, 8 miles in length and nearly 5 miles in width, at the southern limit.

Included in this territory, and with the same trend, further sub-dividing the wedge, are a North-west break, running the length of the Rhaiadr Valley, and another dislocation N.N.W.-S.S.E. from Rhyd-y-fedw across the Hen-fache, both meeting near Llanrhaiadr-yn-Mochnant: it is this wedge, acting on a hinge, as it were, near Llandrillo, which has brought up round this locality the central Llandeilo rocks.

These lines of dislocation, then, are rather more of the nature of thrust-planes than normal faults.

Breaks in the continuity of the outer tuff-rings are numerous, and many are quite visible; on the South-west corner those connected with reversal-thrusts are clearly seen in the Marchnant Tunnel at Llanwddyn. The faulted blocks comprised in the Hirnant-Penybont fawr district are also well indicated, the two bounding S.-S.W. faults being prolonged through Tuff II (" Craig y Pandy Ash " of Messrs. Groom and Lake) in a westerly direction.

The Llangynnog district is particularly broken by both dip and strike-faults; it is cut off from the acid sheets of Y Garn by the Carnedd-y-ci West thrust on the East and on the North by the mineralised Cwm Orog strike-fault, until recently worked for lead and barytes.

The downthrow here is to the N.N.E. The actual lode, as mapped, has apparently never been reached by the mine-levels, though much effort was directed to that end.

The Cwm Orog fracture has but little affected the succession which dips North here at 17°, yet it has diverted true dip from 26° N. 4° W. to 24° S. 8° W., thus forming a shallow anticline and repeating the thickness of part of the Bala beds in descending order.

There is a series of small faults, for the most part pre-Carboniferous, which cut up the ancient volcanic plateau on the easterly boundary, and which almost invariably hade to the North, yet in some cases the lines of weakness have persisted, as shown by their continuations across the strike of these formations as far as the Coal Measures.

This scheme of faulting, associated, in a comparatively small radius, with the spiral twisting of this shattered district, will be recognised as hardly less important than that existing around Bala.

By far the most important break is that running West from Maesbury Hall to Whitehouse, thence passing to the North-west and cutting out along the strike at least a mile of mapped " ashes " on Mynydd-y-Briw.

Many other important faults in the inner region free from volcanics do not come within the purpose of this paper.

IV. Distribution of the Rocks.

Vulcanicity is represented in some form in many localities in the area, but it is most persistently developed in the highest sedimentary beds of the outer slopes, except where denudation and overfolding have broken the continuity under the massive sandstones of Llanfyllin and Llangedwyn.

Many beds or intrusions exercise but little effect upon the topography, while in other instances marked features of great boldness, notably in the neighbourhood of Cader Berwyn, Llangynnog, Glyn Ceiriog, and Craig Orllwyn, stand out from their slaty beds as evidence of greater durability.

Petrographically, the rocks in the field do not present types of exceptional interest, and, for the most part, over long distances their characteristics are somewhat monotonous. A few type-rocks, however, local variations of main bodies, with an equivalent chemical composition, are emphasized as isolated developments of a magma which produced a general facies similar to that of Snowdonia.

Petrological examination suggests a small but comprehensive classification of well recognised type-rocks, with a sufficiently sharp line dividing each class. In the field the rocks of different localities tend to fall into natural groups isolated enough to assist determination.

The following brief outline will serve to define the nature and geographical position of such rock-groups, and the relation they bear to the general structure. The localities mentioned are nearly all shown on the original One-inch Geological Survey Maps mentioned.

Rhyolite Tuffs: (Peripheral Series.)

This series consists of three strongly marked bands of volcanic tuff and agglomerate which are persistent, but not always continuous, around the outer slopes of the area, and run roughly parallel to the strike of the lowest Silurian beds.

These bands will hereafter, and in order to avoid confusion caused by multiplicity of place-names, be known as Tuffs I, II, and III.* They have hitherto been known as the Bala "Ash-beds," or by the comprehensive term "Trappean Ash" of the Geological Survey. They are much commented upon in the Survey Memoir.†

I. The "Little Ash" of Jukes is the most fugitive and least in importance of the series; it is mapped as a continuous line for a distance of 13 miles, but few indications prove its reality, and one fails to find it where, by the configuration of the ground, it should be best seen.

II. The "Upper Bala Ash." This is the most persistent of these contemporaneous bands. It conforms very regularly to the general dip and strike, and would extend, except where cut out by faults, for a distance of 27 miles on the North and West outer margins.

Although for long stretches the rocks are admirably exposed, frequently long gaps occur in the continuity, either from the cause named or by over-thrusting. Great tracts of deep heather or marsh also occur, and here the indications are few, plotting becoming a matter of uncertainty.

III. Still lower in the series comes the third band, the "Lower Bala Ash" of the Memoir, striking in the same general direction as the first-named, but separated from band II, in the field, by distances varying from one mile to two furlongs, according to changes in levels, dip, or contour. Originally mapped for 19 miles continuously, there are here again extensive gaps to be

* For purposes of reference these correspond in Messrs. Groom & Lake's paper to Pen-y-Graig Ash (I); Craig-y-Pandy Ash (II); and Cwm Clwyd Ash (III).

† "Geology of North Wales," 1866 and 1881 Editions.

accounted for. The band is much dislocated, but, taken generally, it is a valuable platform for any work in the region.

I am unable to confirm the mapping for the final $1\frac{1}{2}$ miles on the western flank near Buarth-glas, nor does it appear possible that the band lies so low in the series as the horizon of the Llangynnog acid-rocks.

Rhyolite Tuffs: (Mynydd-y-Briw Group.)

Two miles North-west of Llangedwyn the bold ridge of Craig Orllwyn rises directly from the Tanat Valley. It forms a commanding feature in the landscape, and on the precipitous northern side yields singularly perfect sections of torsional folding from the North-west. Travelling North-east, the slope of the crest rises to Mynydd-y-Briw (900 feet), thence to the East it forms a flat curve ending in an undulating country on the Llansilin road, two miles North-east of Llangedwyn. The length of the ridge is three miles.

The prominence of this elevated tract arises from the existence of parallel ribs of hard igneous rock which strengthen the structure from end to end, and which have assisted the mass stubbornly to resist denudation, protected the intercalated sedimentary beds during a long period of induration, and combined with these as a resisting buttress to the progress of the North-west fold, evidence of which is here so graphically shown in its relation to the breaking up of this South-east corner of the region.

These two bands must be regarded as disjointed terminations of the Peripheral Series.

Rhyolite Lavas.

The village of Llangynnog, 9 miles from Llandderfel, and 16 miles from Oswestry, lies at the foot of the Millt-yr-gerig Pass, the only highway crossing the Berwyn saddle. It is situated near the head of the Vale of Tanat, about 600 feet above O.D.

The rocks described under this group comprise the bedded lavas North of the village about Craig Rhiwarth, the isolated mass on the South, honeycombed by the workings of the old South Llangynnog lead mines, and occasional exposures over an area of some 64 square miles East and North-east of the Tanat River.

All the volcanic cappings, outliers and outcrops, so noticeable as features of the hills around, were originally mapped as "Trap," but, although the details of each bed and exposure are beyond the present scope, it must be noted that much evidence is found of rocks of pyroclastic nature being associated with flows of true lava.

Rhyolite Tuffs (Lower).

I have not found, in the vicinity of Llangynnog, any rock so nearly approaching in character those of the marginal series, but well developed tuffs do exist in conjunction with the lavas further East and North of Llanrhaiadr-yn-Mochnant, where they occupy basal positions in the eruptive sequence for the most part, but are occasionally intercalated.

The bands on Godor, mapped as "Trap," are tuffs without lavas, and the "ash" of Pen-y-Bryn, South-east of Craig-y-Beri, is a typical spherulitic rhyolite without tuffs. Many more exposures must exist among the old crags than have been found, but the only visible difference, in the field, between the fragmental and lava rocks is a certain saccarhoidal fracture in the former, yet even this guide is rarely a certainty. It would be difficult to say without exhaustive microscopic examination exactly to what extent clastic rocks really exist.

Craig-y-Glyn Series.

The calcareous tuffs of the Craig-y-Glyn/Craig-y-Beri district lie about two miles N.N.E. of Llanrhaiadr-yn-Mochnant, in a small area which, if not by itself an independent uplift, at least represents the rocks of lowest position yet found in the Berwyns.

They are associated with, and underlie, limestone beds which have been identified by their fossils as being of Llandeilo age, and must be closely related to the Arenig volcanic series.

The beds dip to the South-east at 20°, and are well shown in section on both sides of the Iwrch River at "David's Leap."

Other broken and faulted beds further North must come into this group, and particularly the faulted exposures of Rhyd-y-Gau must be included.

A few thin lavas which occur may be interbedded with the fragmental rocks, but plotted results are far from satisfactory.

ANDESITIC ROCKS.

The rocks coming under this heading are found on the extreme easterly boundary of our area. Of intermediate composition, they represent, as isolated patches, the results of former volcanic energy distributed on a large scale. The tract occupied is greatly dislocated, and it is doubtless owing to the numerous faults that they have been mainly preserved.

The andesites are not represented elsewhere in the Berwyns in extrusive form, though in some manner they may possess affinities with the unusual rock-type of Hirnant and Craig-Ddu, but this is not clear.

From North to South the patches are Glascoed (with Craig-Wen), Mynydd-y-Bryn (with Sycarth), Moelydd, and Blodwel Hall; all, with the exception of Craig-Wen, are contemporaneous beds conformable to the underlying Ordovician shales.

They are outliers of some large denuded accumulations from volcanic sources, a considerable extent of which, it may be assumed, is still protected by the overlying Carboniferous and Triassic formations. From the position and direction of dip a relationship might be expected under the Valley of the Severn with the older stratified rocks of the Breidden Hills, the Middletown or Chirbury series. This question, however, I leave in other hands.

Intrusive Intermediate Rocks.

(i) Coed-y-Glyn. These are not of common occurrence. The principal example is the well-known sill in the Glyn Valley where, in common with other members of the marginal rocks, it has attained its greatest development, thinning out to the westward and upwards to the surface as indicated by a few small exposures, and on the valley wall itself it can be traced for two miles.

The stone has long been worked by chambers in the Coed-y-Glyn Quarries, where the general section exposed on the hill-side is very perfect. Overlying Tuff II, and separated by a few yards only, it conforms to the dip and strike in the surrounding sedimentaries. The casual outcrops yield little information, and it remained for the deepening of the chambers to dissect and lay bare the nature of the intrusion and its resultant contacts.*

(ii) Hirnant and Craig Ddu. One turns from the broken pinched-out Peripheral Tuff Series near Llanwddyn on the South-west to this district for traces of its continuity in that long stretch of country lying between the water-parting of the Vyrnwy and the land round Llanfyllin and Llangedwyn. But there is disappointment in the expectation, for here the perplexing mass of apparently bedded sheets affords ample proof of intrusive origin.

The rocks composing this group form a double cluster of hills, separated by a wide flat-bottomed valley, having the hamlet of Hirnant on the South-west, Pen-y-bont fawr on the North-east, and Llangynnog one mile to the North.

he quarries ar closed and the lower chambers flooded.

The hills of Cyrniau, overlooking Llangynnog, Craig Ddu, and Carnedd Illog, are formed partly of igneous bands included in this group, and partly of intercalated shales. They are conspicuous landmarks on the country-side.

The rock-type is of special interest, and apparently possesses some affinities with that of Coed-y-Glyn, near the horizon, of which judging from the position of the so-called "Bala limestone," it seems to lie.

(iii) Craig-Wen. This wooded boss-like prominence is so closely related to the eastern andesites that their dissociation is barely possible in the field. The probabilities are that it is intrusive, as distinct from the lava-flows around, but whether of plutonic habit, or of the nature of a cooled "plug," it is not possible to say.

Intrusive Basic Rocks.

These, with one exception, are sills, disposed in bands of no great thickness between the sedimentary beds, to which their strike and trend usually conform.

They are represented only on the northern and western hills, and are most important in the district of greatest lateral pressure, or at right angles to a line radial from the North-west convexity to the Llanrhaiadr uplift. Generally speaking, all have the attributes of the normal doleritic intrusions of Wales.

(i) Pen-y-Bont Sill. This well-defined sheet crosses the valley of the Ceiriog about two miles North of Llanarmon D.C., and is very low in the series. From the river its extension to the East is traceable along a ridge for about two miles, terminating abruptly at a point a little South-east of Pen-y-Gwely, on Craig-yr-hwch.

Westward of the Hendre Quarry the next outcrop is seen in a gully at T'yn-y-Nant, another at Treceiriog, and one good exposure occurring in a stream-bed at

Dolwen. On an eminence between these gullies the sill forms, with extremely hardened contact-slate, the site of the ancient camp of Mynydd Bach, where advantage was fully taken of the natural defences.

From Dolwen there are few traces and no outcrops to about two miles further West, when the sheet again comes to the surface, but most of its inferred position is covered in deep drift. Some large isolated blocks mark the position on the moorland near Cwm-Llawenog, where the termination is a small spur overlooking the stream, distant from Pen-y-Gwely 6½ miles, its total length.

(ii) Cader Berwyn and Llyn-Llyn-Caws Sills. Approximately upon the same horizon as the Pen-y-Bont Sill, two others of doleritic nature occur 5 miles North-west of Llanrhaiadr-yn-Mochnant. Their strike conforms to the great bend of the strata in this direction, where resistance to weathering has assisted in the preservation extremities. The higher or Cader Berwyn, Sill, has a Moel Sych (2,713 feet).

Both sills lie within the area dislocated by the great North-west thrusts, and are truncated by them at their extremities. The higher, or Cader Berwyn, Sill, has a fairly continuous outcrop for about two miles; roughly parallel with this, and a little lower in the succession, that of Llyn-Llyn-Caws extends for about three miles in a similar direction.

Most of the characteristics of intrusive sheets are exhibited in good natural sections, where thicknesses rarely exceed 70 feet.

(iii) Cwm Dywyll Sill. This sill is important, but frequently obscure in its relations to the sedimentaries and the tuffs from under which it has risen. The rock is first seen a little North of Cader Fronwen, whence it may be traced, mainly by a wide expanse of loose blocks, for nearly six miles in a westerly and later a southerly direction. The dip, as is usual on this corner of the periphery, largely coincides with the slope of the hill; the upper surface is thus revealed, but in greatly broken condition.

A few outcrops, as in Nant-cwm-Dywyll, Nant Ysgeriau, and Blaen Glaswen, form good connecting links on the line of strike; while the slopes of Clochnant, Bwlch-gwyn, and Cefn-Penargor, afford good examples of fragmental exposures. On the latter hill some perfect "greenstone" columns are scattered.

(iv) Carnedd-y-Ci. The hill bearing this name rises on the North-west slope of the main Berwyn ridge, and is interesting as carrying a simple band of igneous material which appears at first sight to bear some relationship to those on the Cwm-Dywyll horizon. This, however, is not the case. This sheet has all the characteristics of an intrusion, and is effectively terminated on the North-east in Clochnant, and South-west in Nant Ysgeriau, by the two principal faults of the area, which traverse the ridge from here, cutting the dolerite sill and later other formations to the South.

On the One-inch Survey Map the exposure is marked as a combination of "Felspathic Trap," "Ashes," and "Greenstone." Actually it is much more simple in structure and composition, and may be resolved into a single band of a somewhat unusual rock not hitherto found elsewhere in the region.*

The total length indicated in the field is $1\frac{1}{2}$ miles, and no tuffs were discovered in association.

(v) Springhill Wood. In the gully in this wood (near Pandy-Glyn) is a small outcrop which has apparently escaped observation; it lies on the strike of Tuff III, for which it has been mapped, and is cut by a nearly East-west fault. Of doleritic facies, the rock should come under this group, but the type has not, to my knowledge, been met with elsewhere in Wales, certainly not in the Berwyn.

*See pp. 91-98.

The outcrop is insignificant, and boundaries entirely hidden; the type is intrusive, despite the lack of contact evidence.

(vi) Millt-yr-Gerrig. The irregular patch of basic rock lying in the broken ground between Craig-blaen-Rhiwiarth and the Pass, is the last intrusion to claim attention.

Lying *above* the horizon of the "Little Ash," it is the only igneous rock found so high in the series, and so near the position of the well-known Phosphate Bed and the Bala limestone; even so, there is evidence to prove an origin at greater depth between the tuff-bands.

Less space is occupied than is apparent on the map a large development of columnar grit having been included and similarly coloured, nor does it extend westward into Trwyn-Swch, nor on the flank of Mynydd-Hafod-Hir, as may be seen in the stream-channel. One good natural section is afforded by the torrent bed of Llwyn-gwern, where the habit is seen to be more dyke than sill. Here it cuts across the sedimentary beds, and is probably associated with a system of intersecting emanating tongues, only partly in evidence. Between the stream and the Bala Road the mass assumes a boss-like form, partly visible at the surface. The area is further complicated by the presence of included rocks of acid-type, simulating in appearance the tuffs described.

V. Detailed Description of the Rocks.

A. The Rhyolite Tuffs.

(i) Peripheral Tuffs and Agglomerates.

Tuff I. This narrow band is found in few localities, and its continuity is rarely apparent in the field. At Bryn, East of the Glyn Valley, is a small exposure in a quarry, and again, near Craignant Wood, some broken exposures are visible.

I have long held the opinion that these belonged to Jukes' "Little Ash," and not to the "Upper Bala Ash," though seemingly on the strike of this; the conclusions of Messrs. Groom and Lake,* in their clear exposition of the geology of this neighbourhood, go to prove this fact and the southerly throw of this band by the Cae-mawr fault.

In the valley itself no trace exists, but on the West wall a small weathered patch appears at Pen-y-Graig farm. From here it is faulted out, or concealed perhaps by thrust-planes,† for a distance of 4 miles, when at Dolydd Ceiriog it presents the first obstacle in a fine series of falls.

As a band, rarely thicker than 6 feet, it next traverses the steep slope under Pen-Plaen, and is traceable over Pen-y-Bwlch to Pont Rhyd-y-rhyd; good outcrops occur here on both sides of the Llynor. The best exposure lies on Trum-y-Wern, Llandrillo, in a well-marked dip-escarpment, whence by ridge or depression it is followed to a feature under Blaen-y-dre farm.

Further than Cadwst the sheet is not again seen, where the position might be inferred, for over 20 miles, when it is picked up again on Craig Orllwyn.

There is one dominant rock-type common to all the members of this group, so closely uniform in character, habit, and structure in the field and petrographically, that it will be more convenient to describe it in referring to the other bands in detail. At every localised exposure this band maintains the type.

In no case are the diversified rocks seen elsewhere found within it, the final product of this last phase of volcanic activity.

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* Op. cit.

† Ibidem

Tuff II. In tracing this "Upper Ash" along the strike from the Limestone escarpment, it is seen that the Ty'n-y-Rhyd outcrops are not part of it. Messrs. Groom and Lake* are of opinion that the Cae-Mawr fault has carried it to the South to where, a little South-east of Llechrhyddau, its only representative is the bold exposure called "Craig," yet it is not easy to explain why, a short distance further South, Tuff III should be so little influenced by a fault of this magnitude.

The "Craig" rock, composed of large fragments of red felsite and broken slate, approaches nearer to the type of Tuffs III at Cwm Clwyd than to the mineral composition of Tuffs II in any of its outcrops.

From the fault East of Cae-Mawr Wood field relations are complicated by extensive faulting as far West as Ty'n-y-Pystyll, 3½ miles; the features of the gullies of Ty-Nant and Nant Iowerth, where, dip and slope coinciding, admirably eroded sections are afforded; the complex faulting near Glyn Valley and the mapping over Gelli to Hafod-y-Gerrig should be accepted as they stand, as a result of large-scale plotting, in the paper mentioned.

Further repetition as to details appears unnecessary, yet the China-stone quarries of Cae-Deicws, Pandy and Craig-y-Pandy, on the line of strike, seem to suggest an origin more deeply seated than former superficial layers of volcanic ejecta.

With the exception of this felsite-like rock and some diversified types in Pandy quarry the tuff up to this point is of a dull and monotonous character.

In the Ty'n-y-Celyn area the band is thrown to the North-west by a fault, another cutting it out close by, leaving away from the normal strike a bold and castellated prominence. The strike now changes direction

*Q.J.G.S., Vol. lxiv, p. 585.

to the South-west. For some miles along a sinuous line fragmentary evidence serves as a guide, but over much of the ground, even should the sheet persist, it lies concealed under peat and marshy land, especially is this the case in the turbary of Y Fawnen. Low hills denote the position above the deeply eroded Dolydd Ceiriog, to which it descends by gentle declivities to form the feature of the second waterfall. Towards Corwen outcrops are not numerous, but in Nant-Rhyd-Wilym, Blaen Llynor and on Trum-y-Wern fissile felspathic slabs and outward dipping escarpments are in evidence. The Cadwst ravine, near Llandrillo, shows a strong development, and from here exposures are in force along the slopes of Ty'n-y-Nant and Rhyd-Gethin to the serrated spur of Crechwyl. Continuing without a break to Craig Wen a fine escarpment ends in a mass of broken blocks on Bwlch Millt-yr-Gerrig, whence the outcrop is continuous to the valley across the precipitous side of Craig-blaen-Rhiwiarth and Castell. Both sides of the Pennant valley yield good sections of the dominant compact rock, and, while its position on Moel-di-Moel is mainly a depression, it forms a rocky summit further to the South, an exposure poorly maintained to the intensely hard underlying slate of Pystyll-cwm-llech below.

The band persists for another $3\frac{1}{2}$ miles, exposed here and there, often indicated only by hard, but unaltered, contact-beds, always characteristic, and frequently dislocated by minor faults, the principal of which extend to, and influence, the complex mass of repeated Hirnant rocks. A fault ends this sheet, where it is repeated by overfolding in a small anticline at Bryn-du, 5 miles N.N.E. of Garthbibio.

The former southerly continuation was thrust back and overwhelmed by earth-movements which impressed upon all local beds a dip nearly approaching the vertical; the folding back of the sheet into an anticline near the final "pinching-out" at Marchnant Reservoir is quite traceable on the moorland. The rocks, of the prevailing type, are of little interest, and they adhere to the characteristics of nearly every outcrop of this long traverse.

Through the courtesy of the Liverpool City Water Engineer, permission was granted to examine the Tunnel leading the Marchnant water to Lake Vyrnwy. This was driven, nearly East and West, for 1 mile and passes through the main sheet and its repetition, a North-east fault with a downthrow to the North dividing. Structural dislocation of the beds as seen beneath the surface is not as great as might be expected, but all show a considerable amount of thrusting and shearing parallel to bedding-planes, and much lenticular slate is included in the volcanic beds.

The Bala Limestone, if in its usual position, must be pierced by the tunnel, and is probably concealed by the entrance masonry.

Geikie* says, in writing of this second "ash-sheet":—"The same band, but much more feebly developed, has been traced through the faulted country on both sides of Bala Lake." This apparently is so. The writer has visited every outcrop, and from close examination there is strong ground for believing the rocks in question to be practically identical with those East of the Silurian syncline.

Tuff III. This is the only tuff formation in contact with the limestone or covered by the talus.

Near the Springs and in Cefn-Coch wood the broad disjointed strike is rather indicated by loose blocks than by actual outcrops. Further West, at Llechrhyddau, it can be studied on the steep banks of the Mordda river, where it is seen to be greatly disturbed by complex faulting, though not greatly affected by that of Cae-Mawr.

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* "Ancient Volcanoes of Great Britain," Vol. 1, p. 219.

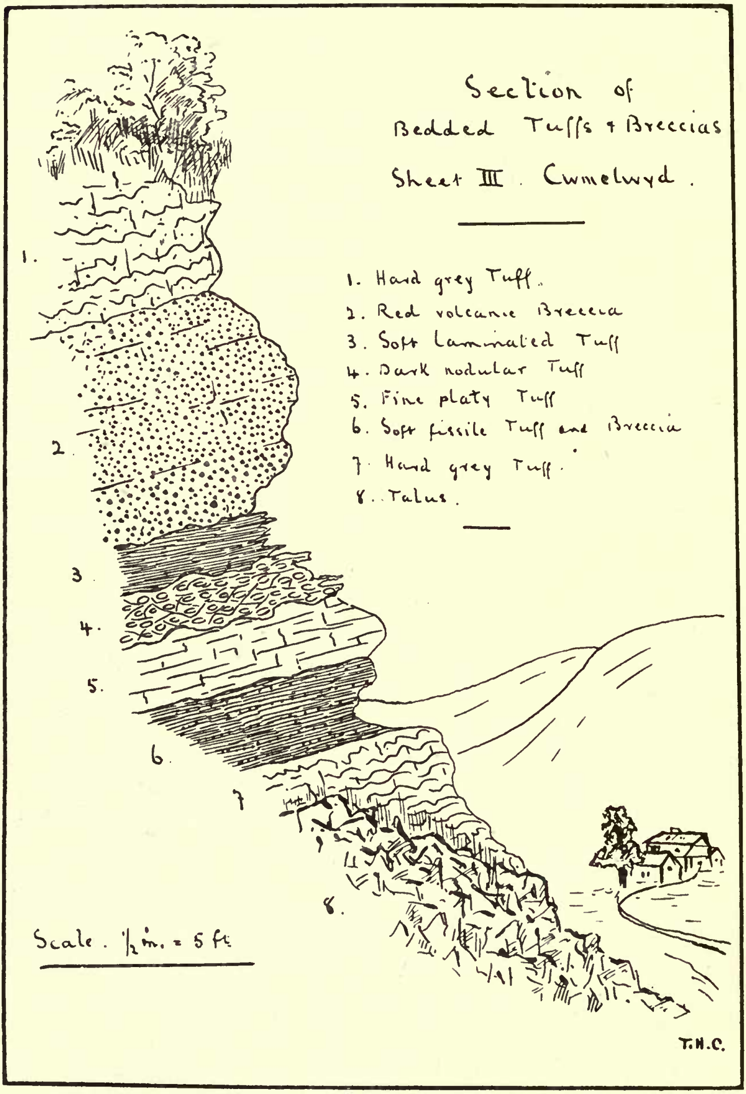
Section of
Bedded Tuffs + Breccias
Sheet III. Cwmelwyd.
1. Hard grey Tuff.
2. Red volcanic Breccia
3. Soft laminated Tuff
4. Dark nodular Tuff
5. Fine platy Tuff
6. Soft fissile Tuff and Breccia
7. Hard grey Tuff.
8. Talus.
1.
2.
3.
4.
5.
6.
7
8.
Scale. ½ in. = 5 ft.
T.H.C.

Fig. 1.

Over the woodland to Springhill the position must be inferred, no outcrops occur in the reedy marshes and deep heather; a good section is presented, however, on the road through Springhill wood, whence follows a nearly continuous outcrop over Gwasted Mawr to the base of Cwm Clwyd, a lateral valley of the Ceiriog. At the top of the Cwm a large isolated mass of rock lies in place, this can bear no relation to Tuff III, and is explained by Messrs. Groom and Lake in their solutions of the thrust-effects over a large extent of this ground. A fine worn craig overlooks the Ceiriog at this point (fig. 1), of which a detailed section is given to show the disposition of the various bedded tuffs and agglomerates which make up the compound sheet. This sheet is found to end abruptly, for the time, at the top of Coed-Erw-Gerrig. Two miles of enclosed pasture land to the West show no trace of it; but on the open moor it is picked up near Tomen-y-Gwyddol, South of Llyn Gloyw-Bach, and near the Carn small outcrops are noted, as again in a small quarry near and in a hole sunk through the slates for water. Weathered blocks then lead in the same direction to Rhyd-Caledwynt, but long gaps without traces continually occur. The strike next swings in long curves alternately North-west and South-west to North of Hafod-Wen. Under Moel Ewig is a clearly seen North-south fault, the rock being shown on both sides. Thence over Craig Fawr, as a very narrow band, down to the deep ravine where, higher in the series, the stream exposures of Tuffs I and II are so well seen. At Swch-cae-Rhiw the bed is but 8 feet thick.

Good exposures now become scarce until we find an important rugged mass on the hill between Cader Fronwen and Bwlch-y-Fedw. No other formation occurs in the Berwyns quite similar to this, it is unlike other modification of Sheet III; its characteristics are strongly-developed platy rectangular jointing, level bedding, compact slaty cleavage and large dull flint-like enclosures. The local general dip is conformed to, viz., about 40° N.N.E.

Following fair exposures southwards, down Cloch-nant and crossing Nant-cwm-dywyll and Nant Ysgeriau, the boundaries between "ash" and "greenstone" must be arbitrary, but are possibly in contact. To Yr Aran and Craig Wen the same remark applies.

Below, in Blaen-Glaswen, the association of the members of the dual formation becomes uncertain, and near Post-gwyn is resolved into a confusion of loose blocks of dolerite and tuff, with separating lines difficult to define.

I am of opinion that neither the intrusive rock nor the bedded tuffs extend beyond this point, and that, owing to some reason, Tuff III is not again met with.

The rock-type constituting the bulk of the three formations represents, in each phase of eruption, a steady deposition of volcanic fragmental material of uniform composition over a wide area.

When fresh it is pale-grey to greyish-yellow in colour, at times dark grey; compact and fine grained but always, the hardest examples not excepted, possessing a certain fissility parallel to bedding-planes or a secondary cleavage of about 38° oblique to these. In the latter case disintegration proceeds rapidly on exposed surfaces, in the former decomposition sets up a creamy whiteness which penetrates to considerable depth. Fracture is usually fissile with liberation of much dust. Crystalline minerals, well seen under the microscope, are not often clear to the unaided eye.

In the matrix are found other varieties of "ash"; some are quite local, many in small patches, unrepresented elsewhere; others occur in streaky beds, thinned or pinched out, and of different nature from that of their surroundings.

With regard to certain contrasts observed, microscopic examination alone shows these rocks to be members of the same group, so little do many resemble the prevailing type of pyroclastic rock, but no process of dynamical stress or chemical alteration has succeeded in entirely obliterating the general family resemblance and the stamp of their common origin.

Texture varies from greasy and vitreous-looking, cherty, harsh and gritty, flinty to chalcedonic, comminuted and crumbling to dust; also talcose at times, when the rock consists of a sandy steatite. Often a compact felsitic stone grades into a mass of incoherent yellow scales, hardly recognizable as of the same bed in altered condition.

All colours are represented, a usual one is silvery greyish-yellow; all gradations are found in the dark greys and blues. Shades in red or yellow may be referred to the decomposition of the hydroxides of various scattered minerals; some reddish types, however, are coloured by pink calcite, red orthoclase or blood-red felsite fragments. A few are dark with slate fragments, others white with excess of carbonate of lime.

Types, distinctly fragmental under the microscope, show no trace of this in the field; many are influenced in colour and texture by other rock inclusions; which may constitute the bulk. Such are baked slate, grit, rock quartz, quartzite, rhyolite, felsite, andesite and other tuffs.

It must be inferred that, in the case of local development of coarse breccias, the source of origin was not far removed; in such rocks little fissility is displayed, but a rough parallel jointing merges occasionally into the felspathic schistose variety seen well on Craig-y-Pandy.

Here and there on the moorlands are found included thin schistose bands composed of grit, slate, and red felsite fragments, rocks which after deposition have been crushed, foliated and re-cemented under pressure, and now appear as attenuated lenticles defined by lines of kaolin, talc or mica. A basal variety of agglomerates, sparsely developed near Glyn, is composed of red and grey angular felsite in a matrix of blue chalcedonic material.

Nowhere do the rocks suggest the abundance of quartz and felspar phenocrysts constantly in evidence in thin sections. The few felspars noticed are usually red or white orthoclase, dull and turbid; the largest measured 4 mm. in length, but, as a rule, they are much smaller.

From the paucity of plagioclastic crystals in hand-specimens they would seem to be subordinate, such is not naturally the case. They are water-clear when freshly broken, but leave much lime-carbonate on weathered surfaces. Idiomorphic quartz is generally visible, while patches of chalcedony and semi-opal occurs in cavities in leached-out softer rock. Vesicles and lithophyses, with chloritic filling, may be met with, but such structures are simulated, and although evolved from the action of imprisoned gases, do not correspond in detail to those in molten flows.

Pseudo-nodular structure is seen in good examples from Cwm-Clwyd, Clochnant, and Fawnog. In the first instance the little ovoid bodies lie along the upper surface of an interleaved tuff, in the others in sporadic colonies in a compact matrix of denser material. Nowhere does evidence exist of altered sedimentaries in direct contact with the tuff-beds; although slates and grits are always harder and more compact, there has been no change by heat.

Regarding the large truncated lenticular masses of slate, so often seen in the compound tuff-beds, there are two alternatives to consider:—

(*a*) The forcing of attenuated slate beds along lines of weakness in the tuffs at a time when all regional sedimentaries were converted into a vast lenticular complex.

(*b*) A somewhat reversed process; the disruption of thin intercalated slate beds, followed by pinching-out and shearing overfolds of the upper portions of the main tuff-band.

No scheme of succession can be laid down on the question of stratification. The thickness and alternation of beds of every texture vary, and pass into each other within a few feet.

The fine dusty and compact felsitic beds mix indiscriminately with the clastic beds on a large scale, but false-bedding, either by current or sub-aerial action, can be made out on the face of a few escarpments.

Lastly, during many years' examination of these ancient sheets, the writer has not met with a single instance where it was possible to presume the existence of contemporaneous lavas. That the lavas, at the base of the series, may be distantly related to these higher tuffs there is every probability, but it is clear that the outbursts responsible for the formation of those tuffs were of a purely fragmental nature.

Microscopically examined, the series becomes resolved into a few defined types, despite the multiplicity of hand-specimens.

Variations or combinations of these are found, but the breccias and agglomerates do not pass under these headings. They may be classed as follows:—

1. Fine-textured, compact rock, dusty and friable at times.
2. Very hard, consisting mainly of comminuted pumice.
3. Matrix as above, with felspar and quartz phenocrysts.
4. do. do. felspar phenocrysts only.
5. do. do. quartz phenocrysts only.
6. do. do. felspars (plagioclase in excess).

Three features of note are the freshness of felspar crystals, the idiomorphic quartz, and the scarcity of other included minerals.

Matrix. The ground-mass is most often a chaotic mass of irresolvable material, and is seen in ordinary light to be pale-yellow or colourless; translucent crystals are outlined, and darker areas bounded, by what appears to be fluxion-structure. Polarized light breaks up the transparent slides into granular structures of infinite variety and degrees in solidity of texture; a glance over a long series of slides, however, emphasizes the uniformity in general characters, and stamps them as rocks of detrital origin, even when not definitely agglomeritic.

The normal base polarizes feebly, the dull undeterminable particles transmitting little light; when very thin there remains still a finer interstitial dust which is practically inert. The same type (121),* on the other hand, may polarize brightly, the medium in such case being an intimate admixture of calcite, volcanic dust and comminuted pumice.

Some specimens, otherwise smooth and compact in texture, exhibit, when sliced, sudden alternations of the matrix, and here crowded in small spaces are patches of dull structureless base, anisotropic bands and lenticular and felsitic-like or micro-crystalline areas; at times the latter occupy the whole slide (296), or are replaced by a quartz-mosaic.

This again in places shows an arrangement of knitted felspar and quartz, a mechanical mixture of crushed phenocrysts and secondary silica.

A semi-isotropic base (156) is also seen, where small patches or granules and fine dust, having glassy characteristics between crossed-nicols, are found to be perfectly translucent in ordinary plane light, but it is probably colloidal or chalcedonic silica. Semi-opal is present in small quantity, as proved by staining uncovered slides with malachite-green. Yet another type of matrix consists wholly of pumiceous fibres, sericite, and carbonate of lime. Shearing and movement of particles and grains under compression and thrust are

* The numbers in brackets refer to the microscope slides in the collection of the late Mr. Cope.

clearly shown by a brightly polarizing secondary mineral, everywhere abundant. This is seen in patches (175) or curving filaments; felspars may be replaced by the mineral in scaly form, and by its aid distortion of the rock-mass and boundaries of included fragments are defined by sinuous, faulted lines. Crush-flow or breccias are thrown into relief by the same medium, and ragged filamentous folds wrap round idiomorphic crystals as if a true flow-structure. This wisp-like mineral is sericitic in character, possibly a combination of sericite and a talcose substance which follows movement-planes. Some obscure secondary basic silicates, indeterminable, are also associated.

With such evidence of stress the abundance of well-preserved phenocrysts from destruction is remarkable, as also the small amount of orientation along such planes.

Reviewing the rock-bulk as a whole, it would appear that, as local variations indicate, the three bands were laid down from more than one vent. They represent three long phases of intermittent eruptivity where the fragmental material ejected was singularly uniform in character.

Mineral Constituents.

Felspars. These are widely distributed as phenocrysts or fragmental forms in every rock-type. There is no rule as to their deposition, except regarding size in connection with distance travelled, nor data to explain the preponderance of acid felspars in some localities, more basic in others, or an assortment of both.

The potash group is important with individuals comparatively large and well developed, but taking a wide range of specimens the lime-soda group predominates.

Orthoclase phenocrysts have usually a large development of the clinopinakoids, and consequently occur in the broad tabular shape; if in hand-specimens crystals are somewhat clouded, sections cut parallel to the principal axes are seen to be as clear and transparent as sanidine (170). When cut parallel to the basal plane there is also considerable breadth in construction, the clinopinakoids (010) being often perfect. A few plates attain the dimensions of 7 × 4 mm.; when of this magnitude typical forms are usually good, they are structureless, and extinguish with uniformity. Simple twinning is normal, good examples (204) occurring on (010); the compound type after the Baveno law is also met with (206).

The Carlsbad twinning prevails with a well-defined medial line, but many large plates occur, in which between crossed-nicols all parts extinguish simultaneously. When prismatic cross-sections occur, in many cases without structure, the twinning plane is seen when cut at right angles to the "*b*" axis. The monoclinic prism is often perfectly shown.

Cleavage, set up by stress, is rarely perceivable, in some slides it is faintly traced by oblique transmitted light when the reticulated figure is seen. Cross-hatching, in places, suggesting microcline, is probably due to the incipient breaking up of a crystal. Cleavage measured on (010) $\angle$ 87° 20′. Stress is also revealed by irregular polarization and strain-shadows in the case of bent or faulted phenocrysts.

Apart from typical crystals, many are rounded by attrition, or take the form of splinters, others attacked and resorbed by an original magma; a few are broken down to form a mosaic with secondary silica. Some are crowded with enclosures, usually mica, zircon, rutile, magnetite, dust, and a little glass. Lime-carbonate, chalybite, or the matrix, is commonly pseudomorphous.

Plagioclase. Phenocrysts of this group rarely exceed 1·50 by 0·75 mm. in dimension; as noted, they preponderate as individuals, probably not in bulk.

Usually imperfect as worn or broken crystals, many forms still remain to offer good data for optical determination. Like the potash group, these are broad clear crystals with little structure but unquestionable oblique extinction. The tests point mainly to oligoclase when extinctions are determined from the edge 001:010. The average of a great number on {001} was 3° 22′; perpendicular to {010} 7° 4′. Generally well shaped, it is the most conspicuous member of the group, and has better resisted magmatic corrosion, chemical alteration, and pseudomorphous replacement. Zoning is seen in some cases (169) where outer layers seem to be oligoclase and the inner a well-preserved basic variety.

Striæ of twin-lamellæ are minute and abundantly repeated. Poor interference figures are shown, but dispersion when seen is fully crossed = $p > v$.

Labradorite is next in importance, and more easily determined; long plates and narrow blades are characteristic. Corroded edges frequently interfere with extinction angles, but polysynthetic twinning is not interfered with; lamellæ are broader than in the oligoclase. Traces of cleavage, about 93°, are very faint. Tabular basal sections give the best angular measurements, a mean reading {001} = 5° 6′, and {010} = 15° 53′. Pseudomorphism by substitution is very common, many crystals being mere skeletons.

Andesine is a rare constituent; angular measurements approximate to oligoclase, and some care is needed in determination. The crystals are clear, with weak relief, rarely large, and with broad lamellar markings. One good example (208) is cut in the plane of the "*c*" axis, where andesine, with regard to optic axes and crystal faces, is typically expressed.

Albite. Although sodo-calcic felspar is recognised, it is a rare constituent; small groups of crystals were found in one slide, but idiomorphic forms are, for the most part, absent. The flame-test is characteristic, the soda reaction being very strong. Compound twinning and that on the Carlsbad law are typical; in the latter case it might be taken for orthoclase, when twinning is absent, but for the low refractive index.

Extinction angles on sections perpendicular to { 010 } giving + 18° 5′ : 21° 3′ are confirmatory, as also the cross-twinning resulting sometimes when the brachypinacoid is the twin and composition plane.

It is probable that the average composition of the triclinic felspars lies between:—

$Ab_6\ An_1$—$Ab_2\ An_1$, and $Ab_1\ An_8$—$Ab_6\ An_1$: in which $Ab = Na_2\ Al_2\ Si_6\ O_{16}$ and anorthite $= Ca_2\ Al_4\ Si_4\ O_{16}$.

Q u a r t z is present in idiomorphic form, largely in excess of the felspars, and like them is devoid of orientation. The high general acidity of the tuffs is doubtless due to these large enclosures. While many crystals still retain perfect crystallographic outlines, some have suffered deformation by crushing, and now form secondary granular areas.

An endless variety of forms, sections of the prism and pyramid, is present, the largest prismatic section measured being 4·25 × 2·52 mm. The majority of these are single-ended, opposite terminations being rough and broken, as if by disruption of some drusy cavity; double-ended prisms with right or left-handed pyramids also occur. There is a frequent form of ovoid rounding, distinct from magmatic resorption, which is suggestive of wearing down by attrition. Sections and skeletal polyhedra (210) of basal planes give often perfect outlines; such sections are isotropic, except where strain produces anomalous double-refraction. Large crystals may be fissured or cracked; in rare cases (169) are phenocrysts with a secondary outgrowth of crystalline silica showing optical continuity.

Quartz is also plentiful as a mosaic, and often indicates old crystal boundaries, rugged and curvilinear masses of granules and wisps and veins following cleavage. Loose crystal aggregates with long prisms are also seen, as if derived from some miarolitic structure.

When magmatic resorption of crystals is so common, it is difficult of conception that the present compact fragmental matrix was responsible for the bulbous and finger-like intrusions. The alternative must be sought for in the result of the law of decreasing basicity during a differential process in the original magma, quartz-phenocrysts so formed being corroded after solidification and before ejection, carrying with them small corroded bays filled with the magma, which even now are often glassy or exhibit the dark cross of spherulitic structure.

The presence of pseudomorphous chlorite, inclusions of pyrites, and parallel lines of liquid inclosures support the theory of deep seated origin.

In rocks laid down from pyroclastic and pumiceous material, minerals accessory to its original crystalline facies are hardly to be expected in force: of those adventitious here only the most stable have endured. They are of little importance, either in number or variety, and consist of : zircon in rounded grains and prisms; garnet in some of the potash-felspars; apatite in minute crystals; sphene in small plates, rare; magnetite dust; abundant leucoxene; ilmenite common, hematite and pyrites occasionally seen.

Secondary minerals are: calcite, ubiquitous and plentiful; chalybite in a few localities; serpentine in patches, grains and wisps; spherulitic aggregates of granules, isotropic or weakly pleochroic, outlined by magnetite dust may be a replacement of hornblende. It is unimportant, but with a little chlorite may be questionably regarded as an indication of the former presence of ferro-magnesian minerals. Epidote is scarce; a fibrous zeolite, fringing some of the lime-felspars, is common, and is probably natrolite. Mica in thin flakes emphasizes crush-lines, and is an aluminous-alkaline variety, probably a hydrous mica of the sericite group. Sillimanite occurs as a few small needles along foliation-planes; saussurite is present, with a little secondary albite at times; talc, tridymite in rare groups of overlapping scales, and opal in hyalitic condition, complete the list.

Cae Deiwcs.

Although on the strike, and apparently part of the mass composing Tuff II, the rock of the "China-stone" quarries, Glyn Ceiriog, is unusual in character; the inclination is to dissociate any tuff from a rock so essentially felsitic in appearance, yet the clear-white, flint-like, translucent rock is still considered to be an "ash." The Quarries are Cae Deicws (upper and lower), Coed-Craig-y-Pandy and Pandy, all now abandoned.

Macroscopically the characteristics are brittleness, hard and flint-like compactness, and strong conchoidal fracture. From white the colour changes to greyish-blue as the margin of the normal tuff is reached; into this, at some points it passes insensibly, except where a North-west fault truncates, to repeat the formation in the lower quarry. The silica percentage is 81·68%. The rock is local and peculiar to the Glyn district, that of Cae Deicws, a sheet 265 feet in thickness, may be taken as representing that in the other workings. It is of an homogeneous pale felsitic nature, distinct from the normal schistose tuff which surrounds it.

Under the microscope the matrix of the white rock resembles somewhat that of the normal tuffs, though considerably finer in grain than in most localities, when consisting of comminuted pumice; but thin sections cut from the central columns show this ground-mass to be purely felsitic (as the term is applied to an intrusive), an indefinable felspathic admixture with quartz.

Included felspar and quartz phenocrysts are identical with the rest of the series, but included rock-fragments are noticeably few. Messrs. Groom and Lake express the opinion* that the rock is a rhyolitic-tuff. Certainly there are no contact-phenomena, as of an intrusive mass, yet they lay stress on the "thickening" of the "ash" beds where such rocks are found in faulted areas.

Even if the characters of a true intrusion are absent, it might still be possible to conjecture that, granting the basis of the sheet to be a contemporaneous tuff, opportunity was afforded during the period of complicated disturbances affecting the locality for the injection into crush-areas of a siliceous solution, of more or less viscosity, which, permeating the mass, has impressed upon it its present exceptional character.

I am still to be convinced that a portion of the centre of the tuff-band is not of later date than the main body.

The brecciated margins of the Coed-y-Glyn sill and the mass of Blodwel Hall present similar phenomena: a matrix of colloid silica, in both instances acting as a bond for incorporated fragments.

Rock Fragments included in the Tuffs.

The rock inclusions selected from an average of specimens may be described as follows:—

Slate. Angular and relatively fresh, or baked, porcellanised, and with fused edges. Often as rounded masses (209) indurated, structureless, and transmitting no light. Lamination traces rarely seen. Colour mostly a dull brown.

Sandstone. Infrequent, small angular fragments. Quartz grains (rounded) in a bond of secondary silica and ferric-oxide. Colour pale yellow.

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* Op. cit., p. 564.

G r i t . Quartz-grains all angular, with secondary outgrowths. Rock baked white and intensely hard.

L i m e s t o n e . Arenaceous, greatly altered. Volcanic dust prevalent. It is partially decalcified.

G r a v e l (?) Small ovoid bodies of many different textures and natures. In part small volcanic bombs and lapilli must come here.

V o l c a n i c t u f f s a n d b r e c c i a s . Unaltered fragments of the prevalent rock in a finer-grained non-porphyritic ground-mass.

R e d f e l s t o n e . These fragments, when in profusion, lend a granitoid appearance to some rocks in the field (Cwm Clwyd), and resemble pink orthoclase. Microscopically, in ordinary light, a certain depth of colour aids detection, otherwise they are translucent. Micro-spherulitic structure gives black crosses of unusual clearness; the rock approximates to the spherulitic rhyolite of Llangynnog.

G r e y f e l s t o n e . Yellowish-grey, an even complex of felspar and quartz; when idiomorphic the felspar develops micro-pœcilitic structure.

A n d e s i t e . (*a*) (204-210) Comparatively unchanged fragments abound in traces of hornblende and plagioclastic felspar in a base cryptocrystalline to microlitic. The felspar is fresh and clear (oligoclase). This rock is identical with the volcanic rocks of Glascoed and Moelydd.

(*b*) Similar pieces, round or sub-angular, of an andesitic (trachytic) facies, partly altered and re-fused. The rock is an augite-andesite.

V e s i c u l a r r h y o l i t e . A remarkable inclusion in the sheared tuff at Clochnant (Cwnyd) was a block 4 × 6 inches, black, and dense in structure. Ground-mass micro-felsitic with polarization spherulitic and dark. In veins of inert matter (colloid silica) are small ovoid bodies built up of well-marked rings, concentrically arranged and polarizing collectively. They form a dark border to a core of dense material, with frequent felspar crystals on which they are moulded.

An exceptional interbedded type of rock hardly comes within the acceptance of the word tuff, and deserves special mention. It forms a portion of the compound tuff-sheet III, exposed on the escarpment of Cwm Dywyll, and is of local occurrence. The term nodular-rhyolite has been applied to this rock, which, if interbedded with volcanic tuffs and breccias, might with some reason be regarded as a lava-flow. The microscope, however, disproves this theory. The rock is soft, dark brown in colour, and studded on bedding planes with little raised masses, once spheroidal, now mainly ellipsoidal; the largest dimension was 8·9 × 2·6 mm. It is not possible here to discuss their probable origin, but the following details were noted.

These spheroids reveal a modification only of a prevalent sandy matrix enclosing quartz and felspar phenocrysts and masked by much obscure muddy material; in places this dark and compact matrix reverts, in patches, to the usual brightly polarizing tuff-like type.

The spheroids become darker towards their outer edges, and suggest a commingling of argillaceous sediment with the felspathic tuff during deposition; many give the black cross between crossed-nicols, a few possess a broken felspar for a nucleus.

They may be spheroids of concretions, or the result of exaggerated perlitic cracking through stress, either possible in thick bodies of tuff under certain conditions.

Probably we have here a thin clayey parting formed without cessation of the fall of detrital material from volcanic sources, the two rocks in embryo exercising considerable influence over each other, as regards structure and habit during formation.

Analysis.

The type of the Peripheral Tuffs taken for analysis was the preponderating grey speckled cleaved rock, 19 specimens being selected from localities spread over a distance of 12 miles, and the selection being made with due regard to a normal quantity of free quartz, felspars, &c.

An average sample of the whole, kindly analysed for me by Mr. C. C. Moore, F.I.C., gave the following result:—

SiO_2	75·74%
TiO_2	—
Al_2O_3	12·20
Fe_2O_3	2·60
FeO	—
CaO	2·73
MnO	—
MgO	0·68
Na_2O	1·35
K_2O	2·06
H_2O (110°C.)	0·04
Combined water	0·87
CO_2	2·12
	100·39

Sp. Gr. = 2·637.

These acid tuffs compare with many rhyolites and quartz-felsites, but the alkalies are not found to be present in force. Albite has been shown to occur, and soda-orthoclase is possibly present; the opinion of Jevons,* however, that the "ash series" consist of quartz-keratophyre tuffs does not seem to be justified. Soda is unimportant, potash hardly less so. This, with the scant evidence of former ferro-magnesian minerals and the abundance of free silica in crystalline form, makes it convenient to revert to the older title of rhyolite-tuff (quartz understood), and as such we must consider all the rocks of the triple series.

* Geol. Mag., Vol. xi, p. 13.

Specific Gravity. Separately from Mr. Moore's determination, 163 specimens were tested, the lowest giving 2·598, the highest 2·729; the general mean being 2·638.

(ii) Craig-Orllwyn.

If the acid tuffs persisted on the same horizon round the southern margin, it is clear that they now lie concealed beneath miles of sedimentary beds, for the overfold which reversed their dip also crushed out and obliterated the strike of the tuff-beds. In the Llangedwyn district these emerge once more into prominence. They merit special attention.

The general formation of this ridge is a series of thinly-bedded shaly slates with grey grit-bands, considerably distorted and dipping South-east at high angles. For the greater part of the distance the succession is much broken, often faulted, and sometimes obscure in its field-relations. These sedimentaries carry the easterly thinning-out termination of the Peripheral Tuffs, which consist, as shown, of two narrow, fairly parallel bands contemporaneous with the Ordovician beds and conforming to their bedding and dips.

The lower band abuts on the Lleinog stream, dipping at 26° S.E., this angle increasing until higher, on the face of Craig Orllwyn, it reaches 57° S.E.

This quarry cross-section of the ridge is illuminating; the sheet measures here 40 feet in thickness; it is underlain and overlain by hard slate, the upper surface being ripple-marked and cracked, with a tendency to exfoliation weathering in blocks.

The ridge on the West is a cliff of 200 feet, exposing extremely hard sedimentaries; a beautiful section of these shales and grits stands out on the crest, the beds having a dip from slightly curved to vertical, or slightly reversed. Near the cliff-edge this band can be traced for 1,000 yards to where it is dislocated by a small North west fault.

The upper band comes out, under Tan-y-Graig farm, 90 yards from the foregoing, and pursuing the same direction, diverges considerably owing to the denudation of the slope; converging to within 30 yards it also meets the same dip-fault.

A similar fault cuts the ridge 500 yards further North at an altitude of 1,029 feet above O.D., at this point 400 feet above the stream. From the Survey Station here the course of the lower band is fairly clear; the lines of the "upper" for some distance appear broken, or the sheet is not seen at the surface. Indications, however, exist, and are sufficiently evident to justify nearly continuous mapping.

Near Mynydd-y-Briw the dual dip increases to 63°, the lower sheet passing South of Briw Plantation to the exposure in Coed Pridbwll, 200 feet wide, the upper under Capel Horeb and so on to Craig Fawr, where their horizontal equivalent is about 250 yards in distance.

On the Craig this sheet becomes practically a denuded vertical wall, 25 feet thick, with a dip 85° South. In a few yards it is terminated by another North-west fault, and does not reappear.

The lower sheet loses 1,340 yards of its length between Coed and Bonc farm through a South-east strike-fault which runs on to the limestone-scarp. It is traceable for another half-mile to Pentre Cwm, the termination on the Llansilin road.

Returning to Tan-y-Graig, it is found that the Carnedd-y-Ci eastern fault constitutes the southern termination of the bands before it becomes lost in the alluvial flat of the Tanat. It is apparent also that the resistance of the ridge assisted the dislocation, and together these forces have further developed a system of virgating faults from a point below Craig Orllwyn quarry.

If, in common with the country North of the great thrust, that occupied by the ridge has been thrown down in the same direction, the position of two isolated bands in the plantation of Tan-y-Graig Planhigfa comes naturally into position as denuded representatives of the two upper peripheral sheets.

Petrographically, and in the field, these rocks are identical; as in the quarry slate lenticles and rounded masses conform to bedding-planes, so in the old working at Planhigfa is the same formation seen.

Macroscopically, these rocks present but few abnormal types, those of coarsely pyroclastic nature are rarely met with, the grain being usually medium, or, as at Wernlâs, almost felsitic. The prevalent rock is uniform (214), tough and compact, grey in colour, and with a rough fracture.

Study of a complete quarry section* has shown a well-defined succession of fragmental deposits of varying grade.

The Wernlâs felsitic type (200) is greyish-yellow and dense, at Planhigfa fissile with a marked oblique cleavage (212). Near the fault occur weathered specimens built of coarse fragments, but suggestive rather of fault-breccia than of agglomerates of bedded habit.

Priddbwll-Mawr yields a clastic type (141) of entirely different character; a pale brown rock consisting of crushed felspar, quartz and slate fragments in a fine-grained matrix; this was not found elsewhere.

At Briw Plantation are found lenticular bands of intercalated shale, barely half an inch in thickness, evidently the remnants of continuous sheets.

One lithological development (213) occurs only near Craig Fawr, lying at the top of the lower band; a fine-grained hard rock, dark grey to nearly black. Orientated

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* T. H. Cope, Proc. L'pool Geol. Soc., Vol. xi, pp. 37-46.

along doubtful lines of schistosity lie dark spheroidal bodies, having a lighter nucleus. A few with exfoliating coats or layers resemble lithophysæ. The bodies are flattened parallel to cleavage direction, and are coated with a black chloritoid substance. It has the nodular appearance of some rhyolites.

In field-work the lines of igneous bands are somewhat obscure; slates and grits are often equally hard, and frequently, on under contact-surfaces, bleached and brittle. Another difficulty is the abundance of felspathic sedimentaries which so often simulate the speckled tuffs. There is at times no line to be drawn between felspathic sediments and muddy tuffs.

At the southern end of all volcanic outcrops on the East the tendency is for all texture to become finer with a more intimate or rapidly alternating association with water-borne sediments.

A strong microscopic similarity is observed between these rocks and those of the outer series, whose general description might well apply here.

Matrix. An identical dusty and obscure groundmass is present, but studded with greater profusion of shattered felspars and idiomorphic quartz. Where the finer constituents consolidated evenly the microscope reveals no structure. Slides are dark, with the exception afforded by highly refracting edges of micaceous flakes. Parts transmitting a little light are possibly richer in comminuted felspars. Some areas are silicified as a later development. Ordinary light, assisted by ferritic staining, shows the distinctly fragmental nature of the rocks, which is strongly confirmed between crossed-nicols, aided by the brightly polarizing sericitic mineral which accentuates shearing. In the case of finer material the evidence points to a quiet settling down of differentiated layers of volcanic dust around ejected fragments or a crystallised mineral, as of tranquil water sifting and minute current-bedding; a structure indicated at times by fine magnetic dust.

F e l s p a r s . The salient feature is the wide distribution of potash felspars in broad clear plates up to 3 × 2·5 mm. in dimensions. Such tabular habit is distinctive, and agrees with that of sanidine when parallel to (010); the principal cleavage also is about 90° on this face. Much-rounded edges by their smoothness suggest attrition by water. Twinning is unusual, the Carlsbad type being the rule; a few forms having a diagonal composition indicate traces on the Baveno law. Abundant also are the plagioclase felspars, mostly in short prismatic forms. O l i g o c l a s e prevails, perhaps more o l i g o c l a s e - a n d e s i n e in composition, rarely is a n d e s i n e detected. A l b i t e , as in the original group, was nowhere observed, but may, nevertheless, be represented by some clear interstitial secondary felspar, of little importance. Decomposition-products along solution-planes are everywhere plentiful.

Q u a r t z . The details of the original description may be adhered to in all respects. Magnetite and liquid lacunæ are perhaps a little more in evidence as inclusions.

O t h e r M i n e r a l s . All the accompanying minerals, noted as being part of the integral composition of the main bodies of tuff-bands, are to be found in the rocks of this, their easterly continuation, and do not call for further or special mention.

R o c k F r a g m e n t s i n c l u d e d . Neither do the larger included rock-fragments, in confirming the previous list, demand more than a passing notice. Slate (201), grits, quartzites, a micro-pœcilitic felsite, and decalcified limestone are all common, also pieces of an anisotropic rock of pumiceous origin. A few fragments with micro-crystalline base, red orthoclase, and quartz are typically rhyolitic.

The slides from Tan-y-Graig, Planhigfa, and Craig Orllwyn quarry show a still finer texture than those of any other locality. Fragmental minerals are smaller, more rounded, and evenly distributed.

Angular quartz grains sometimes establish the rock as an arenaceous tuff; it is, indeed, no easy task to differentiate between a felspathic grit or a quartzose tuff, nor to analyse the varying grades of argillaceous agglomerates.

Nodular structure. The curious nodular bands exposed at Mynydd-y-Briw and elsewhere received an amount of attention hardly commensurate with the result. These spheroids must belong to the large family of nodular structures, of which there exists already an ample literature. Rather less information is afforded by the microscope than by field inspection. They are seen to be solid, non-radiating or fibrous, and without nuclei. The black cross of spherulitic polarization is not present. The scheme of concentric rings exhibited suggests the ordinary contraction-spheroid after perlitic structure of rhyolitic nature.

The facts remain that there is no evidence of intercalated lava-flows, that numerous nodules are only represented by fragments, and that the enclosing bond is truly pyroclastic. Thus, two alternatives are presented; it may signify a re-heating of the mass with subsequent spherulitic cooling under pressure, or the presence of fragments derived from some more ancient lava of acid composition.

The rocks of this group then can be correlated with those of the Peripheral Series, and may be classed like them as rhyolite-tuffs and agglomerates.

Further, since detailed plotting has revealed a more continuous duplication and greater extent of the old mapped "ash-bed," it cannot now be doubted that these parallel sheets are the continuations of at least two ot the beds eastwards, both as to succession and horizon.

B. The Rhyolite Lavas.

This group is interesting from its stratigraphic position at the base of the Bala Series, and on account of its problematical relations with the marginal detrital rocks of similar chemical composition.

Another question which arises concerns its association with the broken group of bedded volcanic rocks around the denuded Llandeilo uplift of the Craig-y-Glyn area. It is feared that comparative petrography will throw but little light on this, though possibly at Llangynnog, at least, we may be confronted with the basal remains of the mechanism which served during long periods to distribute volcanic material of strongly similar individuality.

The geology of the district is less complicated than might appear. The seeming multiplicity or repetition of beds and denuded outcrops are resolved by plotting into three principal sub-groups of lava-flows of variable thickness, separated by slaty beds of great thickness, viz., Upper, Middle, and Lower sub-groups.

They may be traced initially on Craig Rhiwarth, well exposed on the steep cliffs; to the East the many scattered masses and long exposures can be correlated, and the duplicated remnants of flows in the Pistyll Rhaiadr neighbourhood also brought into line.

Thus on Dol Drum, Trum Felin, and Craig Mwn, the horizons of the main sheets are revealed in glacially scoured valleys; on Y Garn by well defined outliers and denuded mountain-flanks; while to the North, on Godor, the relations of the highest and middle sheets are plainly seen.

Further, there are traces, near Gwern Feifod, of a fourth band, thin and attenuated, which is probably a tuff closely related to the second sheet near Tan-y-ffordd

At Llangynnog the rugged isolated crag, rising abruptly from great fields of lead-tailings, at once compels attention. It forms the central feature in a small area of rock identical with the lava-sheet which has been greatly denuded, and is mostly concealed under mining detritus. Local mining traditions tell of a "root" of great depth, encountered in levels far beneath; it is not now possible to verify this.

This small patch, doubtless continuous with, but its connection hidden by alluvium, the lavas North of the village, lies at the base of the North-east slope of Cyrniau, and is bounded by faults East and South. The Tanat stream forms a curved termination on the North-west. On the West it dips below the surface at 20°. The hillside was pierced by numerous adits in an effort to strike the East-west fault, once a lode of exceptional richness. Some of the higher levels show an absence of igneous rock beyond the fault, the spoil-heaps of others nearer the valley prove the piercing of the fault-lode, and that beyond it the lava was met with in force. This is confirmed by the open-cast and daylight-level on the lode at Ty-Newydd; here the fault hades South, the foot-wall carrying a buried extension of the sheet dipping South-west at a low angle, and in the direction of the North-east/South-west fault of Cyrniau. The sheet, on the surface, extends to the first-named fault, as proved by the levels, the underground continuation South being thrown down, exposing slate on the North side. Although the rock around it has suffered displacement, it is questionable whether the "boss" was affected.

The Llangynnog "Neck." A closer examination of this feature shows it to be of considerable importance, and suggests a factor of consequence in local volcanic history. The principal points to be noticed are:—

1. The isolation and elevated position of the rock on a volcanic sheet of its own nature, of which it obviously forms part.

2. The rough symmetry of form, which is nearly circular.

3. Power of resistance to decay and glaciation, due to the harder rock, compared with the denuded ground around.

4. The petrographical similarity to the lava-flows of the locality.

5. The finely developed columnar structure assumed by the mass.

The lava-cap of Craig Rhiwarth shows vertical columnar jointing; in the "boss" this is horizontal, or nearly so, yet inclining to the vertical near the margins

These columns vary from 1 to $2\frac{1}{2}$ feet in diameter. On the East side their longer axes dip North 56° East at about 6°, nearer the base 10° in the same direction. On the North face the dip is seen to be 11° North 65° East, and 60° North 85° East. On the West the slope is 30° North 15° East near the top, and 25° North 25° East below. These bearings are magnetic.

When plotted these directions converge to the North-west to some point outside the present extension of the "boss." The part remaining may be a quadrant of a larger mass, having columns radially disposed from a common centre, which presumably lay in the track of valley-ice flowing eastward to the Shropshire plain, and which was subject to its sapping.

These facts lead to the inference of an old volcanic "neck," the denuded plug only of which remains, the source of origin of the greater part of the rhyolites and their detrital associates now visible on the North and North-east.

There is little remarkable in the general dull and rough appearance of hand-specimens. The colours, when fresh, are yellow, greyish-white, or pale-green when deep-seated and removed from weathering; at Pistyll

Rhaiadr dark-grey. Weathered tints are paler and then spherulites, black in fresh specimens, are spotted white on a darker ground. Structurally they are heavy and compact, with entire absence of fissility; this applies also to the associated tuffs (Cwm-llechog exposure excepted), such crystalline "ashes" being light-coloured, homogeneous, and brighter on fracture than the acid-flows, in which gas-pores, limonitically filled, are frequent on upper surfaces. Idiomorphic quartz and clear felspars are scattered in a felsitic-looking groundmass. Binary twins of the latter are quite common. (198)

The easterly series of the group do not differ materially; they are typically hard and felsitic; an amygdaloïdal arrangement is frequently seen on upper surfaces, the vesicles now containing carbonates. The axes of vesicles lie North-west/South-east. One specimen (150) is a dark greyish-purple, a glassy base carrying small white felspars, best seen on a polished surface.

In the country from Llangynnog to beyond Craig-y-Glyn every outcrop was studied in place, and a large number of slides were cut for examination. The following descriptions will, in a broad sense, cover the general features of the rocks when microscopically examined.

The type is steadily persistent; local deviations occur, but do not interfere with a generalized classification. In ordinary plane light the structural key-note is at once struck, the development of spherulites on a large and perfect scale, well defined by viriditic and ferritic stainings; the radial structure is well emphasized.

Groundmass. So crowded are the globular forms that little space remains for other constituents. As their numbers vary so does the character of this matrix, the resultant varieties being:—

1. Dull to glassy, transmitting very little light.
2. Microcrystalline or felsitic, in the sense of a devitrified rock.

3. Composed of allotriomorphic quartz-grains.

4. Micropegmatitic.

5. Trachytic.

The last is a common type where spherulites are sparse; it prevails up to the outer limits of the group. The constituents are undeveloped microlites of a felspar always possessing oblique extinction, probably oligoclase; their interstitial matrix appears to be singularly dense, and is isotropic in part.

Spherulites in combination with any of the above types of spherulites, as a penultimate stage of devitrification, are all important. Simple forms are the rule. They are built up of crystalline fibres radiating from a central point, which extinguish between crossed-nicols when their long axes lie parallel with the vibration-plane of either prism. The periphery is always well defined, as also the fixed black cross. Occasionally, possibly due to strain, brushes are irregular and shadowy; a few spherulites inosculate on rotation.

Porphyritic felspars exercise no influence on the grouping, but they sometimes form nucleii, and were anterior to the globular formation. From the regularity of outline the general stability of the rock after devitrification may be gauged.

Felspars. These are mostly potash-felspars, in the familiar orthoclase forms, for the most part isolated crystals, large and tabular, and well preserved, but the longer prismatic shape is also in evidence. Simple twinning is the rule, but examples may be found on either Carlsbad or Baveno laws. Fine examples of cruciform interpenetration are also afforded.

Inclosures are as frequent as in sanidine, usually apatite, magnetite, mica, and glass. A cloudy felspar of similar composition is associated with quartz in granular form, when the groundmass is holocrystalline.

Triclinic felspars, never plentiful, assume fairly large platy forms, in which multiple twinning is always distinct. A later generation of microlites, as noted, plays a large part in the knitted groundmass. Extinctions measured from the plane of twin lamellæ and known edges indicate a fairly even, if sparse, distribution of oligoclase, with a little andesine.

Quartz. This is idiomorphic and abundant, giving some fine crystalline sections, and as usual bulbous processes constantly invade. Isotropic basal sections occur in many slides. The mineral, as a product of early crystallization, is generally beautifully developed. Elsewhere are seen mosaics, with or without felspar, and corroded granules. Much quartz enters, in pseudo-crystalline form, into the rock matrix, where it also behaves in the chalcedonic or semi-opaline state as colloid silica. Inclosures in phenocrysts are rare, but strings of bubbles and magnetite dust extend continuously through granular areas.

Ferro-magnesian minerals. Traces exist proving the original presence of some member; such are small monoclinic or six-sided skeleton-forms after hornblende, but these, as also granular patches and wisps of serpentinous and chloritic matter, are simple pseudomorphs by replacement; in like connection there is an undefinable earthy mineral, probably a basic silicate or the "pinite" of some writers. The fibrous state of serpentine is a bright green; some pale yellow microscopic veins are the chrysotile variety, with radial polarization.

Accessory minerals, as in all these old acid-lavas, are few and unimportant. Apatite in slender needles, ragged fragments of sphene, rare biotite in broken flakes, magnetite, a little hematite, and one or two small garnets, are all that reward an exhaustive search.

S e c o n d a r y minerals are equally scarce. Calcite is not common, and is rare in the rocks from the "neck." Epidote at times, leucoxene, ferrite, opacite, and some feebly translucent flocculent matter due to the partial kaolinisation of some felspar.

The mean specific gravity of 58 specimens chosen from various localities and similar in appearance was 2·662.

C. The Lower Rhyolite Tuffs.

Tuffs are not conspicuous in the Llangynnog district, and breccias and agglomerates are entirely absent.

Always fine-grained, the field petrology of the tuffs is very similar to that of the lava-sheets into which they generally merge, and which appear in turn to have been preceded by a deposition of clastic material, now averaging about 100 feet in thickness; much remains in the condition of small denuded outliers.

Lowest of all in the series are four detached patches, lying near the horizon of the lowest Llangynnog lava; at Gwern-Uchaf Farm these are tuffs of a very early period. In the field they scarcely differ perceptibly from those of the flows; weathering, perhaps, sinks a little deeper, leaving a whiter residual crust. Their physiographical features offer no distinctive aid to an effective separation between them and the denser overlying rocks.

The microscopical features, selected from 73 specimens, may be summarized as follows:—

The matrix, dense and structureless, is resolved under a high power into dusty comminuted pumiceous material, partly polarizing in high colours and partly isotropic. A few minute scaly to fibrous patches are probably altered included rocks. The tendency to development of the wispy sericitic and calciferous substance noticed in the outer series is again observed here.

Included minerals. Felspars are essentially similar to those described in the lavas, orthoclase predominating as phenocrysts, many of which are shattered on cleavage glide-planes. Plagioclase is in the short prismatic form, and is invariably oligoclase, as extinctions show. They are not plentiful, nor, indeed, are any felspars at all common.

Quartz is found in large crystals, idiomorphic and often perfect, the quantity differing according to locality. It is the elementary type common to the lava-sheets.

The other minerals present represent those inseparable from the lavas, and they, or their altered equivalents, call for no special comment, zircon and some muscovite excepted.

Included Rocks. Fragments of altered crystalline grits and porcellanite after shale help to build the rock-bulk, the optical behaviour of which is of little significance.

Rounded pieces of a similar lava, curiously non-spherulitic, accompany fragments of altered compressed pumice, and are imbedded in the matrix.

The mean specific gravity of average specimens, taken from widely separated points, worked out to 2·673.

D. The Craig-y-Glyn Group.

Acid Lavas and Tuffs. The tuffs constituting the bulk of the visible rocks retain the characteristics of those around Llangynnog. Substantial differences, should they exist, are obscured by the lime-carbonate derived from the overlying limestone, but such variations must be disproportionate to the general similarity of facies; where alteration is strongly marked it is more by reason of chemical alteration than physical changes.

The volcanic beds have a maximum thickness of 135 feet, rhyolitic tuffs with thin interleaved bands of close-textured, often felsitic, lavas. The relation of the types is not always clear, a certain fissility of structure and lenticular development causing boundaries to override. On Craig-y-Beri this is particularly so, but the entire igneous formation may be fairly traced in detail on the wooded hill of Craig-y-Glyn.

The Tuffs. The true clastic nature of the greater part is shown by the microscope, when in the dark groundmass are seen the usual sparsely scattered idiomorphic crystals of felspar and quartz, which, with their shattered representatives, determine the acid character of the rock. Much of the so-called "ash" is a dusty grit, or fine-grained sandstone, dark grey, with uneven and brittle fracture, calciferous and felspathic in part.

At Pen-y-Bryn the broad "ash" band, as mapped, is a spherulitic rhyolite similar to that of Craig Rhiwarth. It is a dark compact rock, fibro-granular in structure, with much turbid felspar, and is amygdaloidal on the upper surface.

The Lavas. The attenuated lava-sheets, formerly flowing in channels in the tuffs, are of minor importance; they, also, are highly impregnated with calcite, but sufficient detail may be recognised to link them petrographically with the rhyolites emanating from some source near Llangynnog. The highly developed spherulitic structure still persists as a striking feature. One would assume them to be relics of eruption separated by wide intervals of time yielding rocks of like nature and composition as from a common magma. Even so, it must be conceded that the series is of far greater antiquity than anything found at the base of the Bala succession.

The Llandeilo Limestone. This series, overlying the volcanic beds, is about 90 feet thick. The rock is compact, somewhat fissile, fine-textured, and blue-grey in colour; though crystalline in places, it is usually very impure. False-bedding is seen on hill-side sections where the beds are worn and pitted by weathering.

The limestone was obviously a result of slow deposition, and many thin bands, differently coloured, suggest a variable supply of sediment forming the impurities. In the Irwch stream an example was found where 22 distinct bands occupied the space of less than one inch.

It may also occasionally be taken for an argillaceous grit, yet this merges in places into a well crystallised saccarhoidal form, nearly pure, a re-formation minus the impurities of the original decalcified rock. The lower beds still carry certain minerals, especially at their base and in contact with the upper tuff beds from which they are derived.

Under the microscope the normal structure is seen to be a granular admixture of calcite, earthy particles (clay), and sub-angular quartz grains, with other minerals, minute and usually broken. The quartz shows facets of secondary crystallisation. The minerals observed were as follows:—

Felspars (monoclinic and triclinic),

Mica,	Leucoxene,
Apatite,	Limonite,
Zircon,	Epidote,
Sphene,	Kaolin,
Pyrites,	Sericite,
Magnetite,	Chlorite,
Hematite,	Zeolites (Natrolite),
Ilmenite,	Volcanic dust.

The mean specific gravity of the limestone is 2·631.

An average sample treated with acid gave a loss in carbonates of 52·9 per cent. by weight; of the remainder 16·3 per cent., muddy particles, was removed in suspension, and the balance, 36·6 per cent., fractionated with Klein's solution [borotungstate of cadmium] [sp. gr. = 3·28]. The minerals coming down according to density were:—

>3·28 sp. gr.: Quartz (magnetite bearing), felspars (with heavy inclosures), magnetite, sphene, zircon, limonite.

>3·00 sp. gr.: Quartz (limonite bearing), leucoxene, sphene (altered), felspars (turbid and saussuritic).

>2·50 sp. gr.: Quartz (bulk of fraction), felspars (comparatively unaltered), viridite (?granular chlorite), felsite fragments, grit (cemented fragments).

E. The Andesite Lavas and Tuffs.

Descending from the hills towards the lower Carboniferous country, the various patches stand out as rugged or wooded features against the limestone scarp and *en échélon* from the North. Of these, Mynydd-y-Bryn (1,095 feet) is the most marked.

The upper beds of each exposure disappear at varying dips beneath the limestone, which overlies them unconformably.

The denudation of this tract was very great, and even the elevation of the sedimentary beds after their uptilting became enormously reduced before the deposition of newer formations; it follows also that the conformable volcanic area was already worn, and cut to the underlying shale before this took place. These isolated patches are the wasted remnants only of large volcanic deposits whose former extent may only be vaguely inferred.

The group formation is a series of beds of lava, fine and coarse tuffs, breccias, and very coarse agglomerates, all derived from an andesitic magma and, for the most part, in an advanced stage of alteration.

An explanatory word concerning the relative position of each separate mass will be necessary; a microscopical generalization will prove the mutual affinities of the rocks and the justification of a simple classification.

(*a*) Glascoed.

Four miles South-west of Oswestry one steps, on the Llansilin high-road, from the limestone to the rock of the most important patch. On the One-inch Geological Map this is coloured as "felspathic trap," on the six-inch horizontal section as "greenstone."

The main features are the crags about Glascoed-fach and the wooded prominence of Craig Wen (1,000 feet), partially separated by a drift-filled embayment.

Quarries near Pyllau 'r Meirch give considerable insight into the internal structure, but nowhere in these hills can pyroclastic material be detected. The greatest thickness is near Bwlch Sychdiu, and westward at Pyllau 'r Meirch it thins out in broken rock. The area is less than a square mile, the mass resting conformably on shales dipping South at 20°. Under Craig Wen no base is seen.

A fault forms a southern boundary, throwing down the mass towards the North-west; this fracture persists to the South-west across the summit of Mynydd-y-Bryn.

On the North side of Craig Wen a quarry exposes a series of finely developed horizontal columns, 30 feet long, the ends resting against walls of roughly-jointed rock of similar texture. They are straight and well formed, with a slight dip N. 50° W. It is probably a fragmentary quadrant of a circular formation of similar origin to that of Llangynnog. The Craig itself has all the appearance of a "boss." It seems reasonable to assume this to be a vent; it stands in a lava-field of its own producing, and seems to have been responsible for considerable volcanic action in this section. Its petrographical resemblance to the rocks of the other related areas is very close, as will be shown.

(*b*) Mynydd-y-Bryn.

This complicated outlier lies South of the Glascoed area, and extends $1\frac{1}{4}$ miles to the North-west and $\frac{3}{4}$ mile North-east. It represents the last of the rough moorlands to which westwards cultivation slowly succeeds. The general features are the faulted summit of the hill Parc Sycarth tuffs and the declivities of the Bryn district. The stratified volcanic beds on their denuded northern and western margins follow the dip of the underlying shales South at 23° East at about 35°; under the limestone there is a slight uptilt, giving a reversed westerly dip. A strong fault on the South terminates the beds near Bryn, and cuts off the Sycarth tuffs from their continuation on Allt Goch. It is, in fact, the prolongation of the South-east strike-fault, hading North, which cuts out so much of the Mynydd-y-Briw acid tuffs.

A regular interstratified series of lavas and tuffs is seen, a North-South traverse giving a good indication of the succession; thus from the massive agglomerates of Bryn one passes over the breccias and coarse tuffs facing Craig Sychdiu, and the central denuded lava-sheets, to where the Bwlch Sychdiu fault, crossing the mass at Bwrdd-Tre'r-Arglwydd, throws down to the North a large group of fine-grained tuffs.

In Nant-Mawr the lowest lavas and fine tuffs are met with, but the basal beds are not visible; these lavas are of close texture, and very like the finer tuffs in the field.

Near Cross Roads agglomerates are well developed; these pyroclastic rocks are well bedded, the fragments ranging from the size of a small marble to blocks, rounded and sub-angular, three to six pounds in weight. These are the highest beds.

A dusty fine-grained matrix acts as a bond to imbedded fragments and as sinuous partings between beds; it also accentuates false-bedding.

F a u l t s. Regarding the tuffs of Parc Sycarth, disturbance in this locality is not confined to a North-south fault terminating their extremities, for there are several minor slips which explain the great variation in local dips. Further, it must be assumed that from a local point of virgation another fault runs to the North-west, across the strike of the Mynydd-y-Briw acid beds, truncating them, for this group approaches the strike of the andesite tuffs near Pentre Cwm at right angles. It is obvious that the two formations cannot merge, and that a probable line of separation exists under the alluvium of the Cymllaith stream.

Throughout the series the faults hade to the North; they are mostly of pre-Carboniferous age. In the case of continuations through the limestone it would appear that such lines of weakness were unstable in later palæozoic times, and that, while forming part of the complex scheme of folding and dislocation associated with the close of the Bala period, advantage in relief of stress continued to be taken of them at least as late as Carboniferous times.

(*c*) Moelydd.

This small patch, East of Bryn, is protected by, and dips beneath, the limestone scarp at N. 80° E. The latter has a dip of E. 30° S.

The small area remaining has been exposed by the recession of the overlying softer rocks, and further proves the separation by denudation of these outliers before Carboniferous times. The structure is a repetition of bedded lavas and tuffs, the coarse agglomerate of Bryn being well exposed in a hollow of the northern end. The basal shales are found on the steep westerly flank. A small dip-fault, hading North, throws the mass down on the South, while the northern exposures are much shattered, yet exhibit a good section of nearly all the beds in profile.

(*d*) Blodwel Hall.

This tract, about half a square mile each way in extent, and the last detached fragment of the group, lies West of and under the shelter of Llanymynech Hill. An arbitrary boundary line is not possible, but the few rock exposures are aided, under certain climatic conditions, by changes in colour lines on cultivated land.

Tuffs are not conspicuous, and are generally resolved into soil. The highest and lowest exposures in the Llanddu quarries are homogeneous lavas. Stratified beds have the prevalent undulating dips, passing East at low angles, under the Carboniferous rocks, but dipping West in the lower quarry at 50°, and forming a limb of a small syncline ending at Llan-y-Blodwel. False bedding was seen in a thin tuff at the base of the lower working.*

All these rocks, either lava-flows or of detrital origin, present a general macroscopic similarity, accentuated by the presence, in either type, of small bright felspars. Texture is fine and harsh to the touch; recognition is sometimes difficult when tuffs show a platy fracture and lavas are soft and friable. Colours have a wide range, from blue-grey when deep-seated, through greens and yellows to the purple, red, and black of Blodwel Hall. Deep weathering is characteristic, the lavas, when well advanced into the so-called "propylite" condition, showing a white crust several inches deep. Interstitial calcite abounds, increasing in quantity as the limestone is approached.

In the lower Blodwel Hall quarry strong veins of black, chert-like chalcedony traverse the columnar

* In 1901, since filled up.

structure of the main lava-sheet, and carry a breccia of bleached fragments of the andesitic rock through which they rise.

Fragments contained in the agglomerates are usually of lighter colour than their matrix; the coarser grained types are considerably altered by chemical agencies.

The very rough agglomerates near Bryn yield a curious nodular rock, where black spherulites (?) give a striking appearance to weathered masses.

The Lavas.

Under the microscope the lavas are hemi-crystalline, lithoidal, and vesicular, the mineral constituents being glassy felspar, a femic mineral of early consolidation, and a residual acid felspar forming a felted groundmass.

Groundmass. This was probably very glassy, many thin sections now, structureless in ordinary light, remaining constantly dark between crossed-nicols. Such non-polarizing matter is either a dense micro-felsitic matrix transmitting but feeble light, suggestive of slow devitrification, or a granular combination of inert material derived from decaying minerals.

The microlitic base is characteristic of the intermediate trachytic rocks. Here the tiny felspars tend to orientation in flow-lines, but more often lie in felted patches (pilotaxitic structure) with indefinite direction; they occur as finest needles and minute laths with bifid terminations. As extinction is nearly straight the variety is possibly oligoclase. The first minerals to disappear by alteration, they merge eventually into granular and hazy masses of calcite.

F e l s p a r s. Essential porphyritic felspars are of a soda-lime variety, of the short prismatic habit and irregular in distribution. Twinning on the albite, pericline, and, more rarely, the Carlsbad laws, is seen throughout the series. Occasionally, when small prisms are scarce, larger tabular phenocrysts represent them; multiple twinning in these individuals is often beautifullly clear, most often they are structureless or with a simple medial line of separation. There are also bunched, interlocked masses, where crystals exhibit unequal tension or strain-shadows between nicols. Crystals are usually translucent, but as alteration advances lime separates out and saussuritic products supervene. Common inclusions are glass, magnetite, ilmenite, and mica.

In the stout prismatic forms an average extinction of + 5° indicates oligoclase; in the case of the tabular forms the angle is slightly higher, and points to a less acid felspar of the andesine group. Zoned structures, with the alternations of acid and more basic material, are strongly expressed in every fragment.

F e m i c minerals. This group is unimportant, and the distribution of idiomorphic forms quite variable. Original phenocrysts have disappeared, or nearly so; these were mostly hornblende, but two pyroxenes, monoclinic and rhombic, were also present, and traces of all remain.

Hornblende still retains rectangular shapes, hexagonal or long prismatic. The development is strongest in the Craig Wen (Bruce Quarry) rock, and North of Mynydd-y-Bryn. Forms in the vertical zone are usually the prism (110), more rarely the orthopinacoid (100). Measurements of the largest crystals were 2·6 × 0·70 mm.

In extinctions the few determinable were $c = 17° : 20° : 22°$. There is a strong irregular pleochroism, generally with a central nucleus. The colour scheme is as follows:—

α. pale brown,
β. yellow,
γ. pale green,

or absorption $\gamma > \beta >> \alpha$.

Dark resorption-borders reveal in ordinary light a thick dusty margin of granular magnetite. Occasionally a secondary outgrowth of grass-green fibres is seen (109, 110), having the character of actinolite.

A persistent replacement obtains by a green, pleochroic, serpentinous substance with low refractive index. Here the axis colours approximating to *c*, viewed with the single prism, are bluish-green and light yellow respectively.

The vanishing of crystal outlines marks the progress of decay, with segregation of magnetite grains into groups and substitution of serpentine by chlorite, which, after losing colour, yields place to irresolvable pseudomorphs.

Pyroxene. Augite and hypersthene (enstatite ?) occur more frequently in the southern patches, also in conjunction with hornblende in many places. Augite, a pale variety in rounded grains is not common. Small ragged patches, characteristic of enstatite, are also noted. In scattered localities hypersthene was prominent; it is replaced by a pale green pseudomorph, unlike serpentine, and embracing the characters attributed to bastite. The pyroxenes, like hornblende, eventually lose trace of structure, and become effaced by the prevalent chloritized replacement.

Accessory minerals are few in number, and ordinary in type. They consist of apatite, magnetite, zircon, garnet, sphene, and ilmenite.

Secondary minerals also are not noteworthy. They are quartz, semi-opal and chalcedony (in some cavities), mica, epidote, calcite, chalybite, chlorophœite, delessite, leucoxene, pyrites, and zeolites.

If we exclude the Craig Wen "boss" from consideration as a vent, it still possesses some attributes of an intrusive mass. The rock comes, therefore, within the term hornblende-porphyrite, and its modified representative, essentially a lava, on Mynydd-y-Bryn, a hornblende-andesite.

The remaining rocks (lavas), hornblende-free but carrying pyroxenic minerals, are then, according to locality, augite, hypersthene, or enstatite-andesites.

In some obscure localities, such as Llanddu, slides cut from specimens show fluxional arrangement of microlites and rare phenocrysts. Intrusive porphyrites may also occur, but this is not clear.

An analysis, kindly made for this paper by Mr. Moore, is appended. The sample submitted was a fair average of the more hornblendic rocks from Craig Wen and North Mynydd-y-Bryn.

SiO_2	59·64%
*Fe_2O_3	6·71
Al_2O_3	20·41
CaO	2·27
MgO	3·02
Na_2O	4·23
K_2O	0·87
H_2O (110°C.)	0·33
Combined water	2·33
CO_2	0·46
	100·27

* Fe_2O_3 = total Iron-oxides.

Hornblende-porphyrite, Mynydd-y-Bryn, Craig-Wen, and Glascoed, Berwyns. Anal. C. C. Moore, F.I.C.

Specific gravity. Many tests from the andesite lavas gave a mean of 2·724, and from the medium consolidated tuffs a mean of 2·676.

The Tuffs and Agglomerates.

The pyroclastic rocks do not, microscopically, call for much comment. They are nearly all derived from a magma identical with that of the interbedded flows.

The constituents are cemented fragments of varying size consolidated with a dusty matrix into rock masses. Unlike the peripheral acid series, which carry a large variety, the only included rocks here are altered slates and grits.

The large size of some contained blocks in the agglomerates suggests that a vent of origin was not far distant.

A few types deserve special mention; amongst these are: —

(1) The thin tuffs of Allt-goch, which are formed of thin layers of compact dusty material; often the ribbon-like bands measure only 5 mm. in thickness, but still show false-bedding.

The microscope reveals tuffs of extremely fine texture, bright with felspars, and typically andesitic. Comminuted minerals are plagioclase-felspar, altered pyroxenes, apatite, and sphene. Slides are, however, dark between crossed-nicols and clouded with an irresolvable muddy paste indicating contemporaneous sedimentation. The deposit apparently took place in deep water, where an inflow of mud in suspension mingled with the falling "ashes" on the flank of a volcanic island. Overlap by the intercalated shales also indicate the general rising of the floor of such an area.

(2) One medium-textured agglomerate (134) consists of andesitic fragments entirely, with component minerals much altered, rather by dynamic than chemical agencies.

(3) A variety of frequent occurrence at Blodwel Hall (166) is composed of altered slate in small pieces, fragmentary felspars, andesites, and some iron-ores, in a granular matrix of volcanic dust and calcite. Here also, on the South, there is a tendency to fineness of grain, and an increasing amount of sub-angular grit and muddy sediment.

(4) The nodular structure mentioned as occurring in the dense tuff near Bryn is curious in a rock of this description. The isolated nodules are clearly part of the rock body, but in thin slices their borders are well defined. The outer margins are denser in grain, show neither concretionary coats nor cracks, nor is there any semblance of spherulitic structure from a nucleus or otherwise. It may be assumed to be a somewhat abnormal structure developed during a process of cooling in the heated but fragmental mass.

That secondary silicification played an important rôle is everywhere apparent; it is also clear that, from the altered nature of rock constituents, an inference of re-heating must be accepted. The finding of some isotropic prismatic felspars tends to confirm this.

F. The Intrusive Intermediate Rocks.

(1) The Coed-y-Glyn Sill.

This intrusion is of local occurrence, and is best developed near Glyn Ceiriog where advantage was taken of its maximum thickness to excavate a remarkable series of quarries. The exposure is fully visible on the valley-wall to a point where under Craig-y-Pandy the intrusion fails to reach the surface. Its reappearance eastwards is erratic. A small trial-hole on Gelli and a few isolated outcrops under Ty-isaf lead to a considerable expansion (150 yards) in the Teirw River. North of Ty-du the two faults which throw down the local development of Tuffs II cut the sill out in turn.

Beyond a fair outcrop under Tan-y-Pystyll farm to the South-west, and some doubtful exposures on the moors above, the sheet is not seen again. Two small exposures East of the Glyn Valley limit the extension in that direction.

The quarry-face shows the following rocks, in descending order:—

Shattered Slate	14 feet.
Indurated contorted slate	7 ,,
Amygdaloidal brown igneous rock ("roof")	5 ,,
Main body of igneous rock ("granite")	45 ,,
Amygdaloidal igneous rock ("floor")	3 ,,
Baked slate and grit porcellanised	—

While the total thickness of workable igneous rock is here shown to be 53 feet, that in the upper workings is only 16 feet. The overlying contact slate is buckled and folded, and is hard, compact and slightly columnar, conforming to the irregular margin of the sill.

The mean dip of the upper surface was, for a long working period, 20° N.N.W.; some distance into the hill it became steeper, and turning North-west showed 32°, the lower floor rising to meet it. Later the vertical was still nearer approached (71° N.N.W.) in the lowest workings, now submerged, the sill being only 7 feet thick, yet a little lower there were indications of a broader development with lower dip-slopes (fig. 2).

The main rock is massive and compact, with few divisional planes, excepting a tendency to a curvilinear, columnar structure. In places, indicated by minor faults, the stone is crushed and carried fragmentally in broad veins of calcite. In the highest working the vesicular band gives place to a finely developed crush-breccia. Here sub-angular blocks and fragments are enclosed in a bond of translucent chalcedonic material, grey or purple in colour, or at times black; in this the fragments lie, without orientation, bleached to a creamy whiteness. This crush-breccia is interesting as indicating earth-stresses which immediately preceded, or in a sense accompanied, the intrusion.

The minerals found in the quarries were:—Spathic iron, pyrites, chalcopyrite, manganese, blende, cerussite, epidote, chrysotile, calcite, chalybite, stalagmitic iron-oxide, erubescite, green-earth, galena, apatite, chlorite, talc, and quartz.

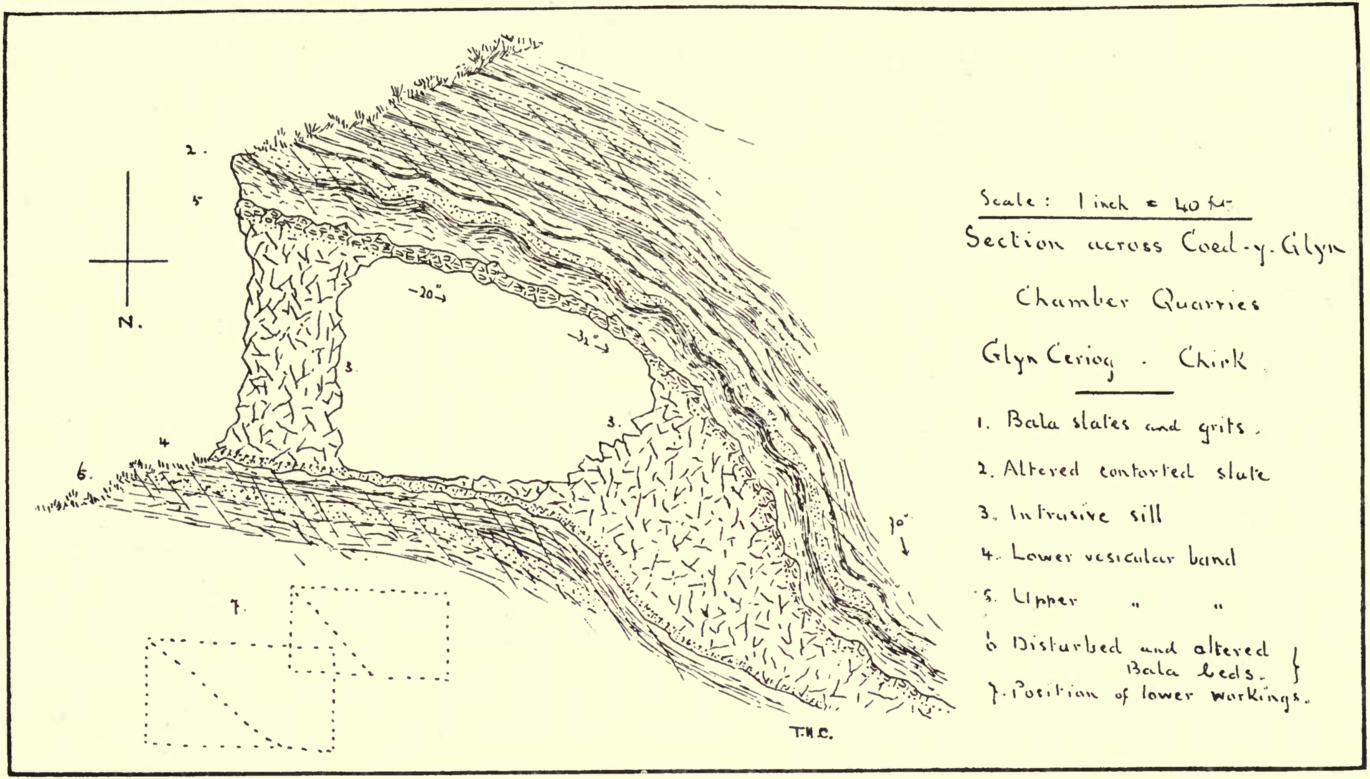
Scale: 1 inch = 40 ft.
Section across Coed-y-Glyn
Chamber Quarries
Glyn Ceriog . Chirk
1. Bala slates and grits.
2. Altered contorted slate
3. Intrusive sill
4. Lower vesicular band
5. Upper " "
6 Disturbed and altered Bala beds.
7. Position of lower workings.
N.
2.
5
4
6.
3.
3.
7.
-20°
-32°
10°
T.H.C.

Fig. 2.

The typical rock is hard, tough, and consistently dense in grain; greenish-blue in colour when fresh, but grey, dark green or purple when undergoing alteration. Porphyritic crystals are small and rarely visible. On the upper outer margin the amygdaloidal rock retains the general characteristics, but is harder and more brittle; it merges insensibly into the main body of the sill. This upper edge formed a safe roof for the workings, and the lower one a natural floor in which the vesicular structure is far less marked. The amygdules lie with their longer axes arranged in flow-direction, their flatter surfaces parallel with those of the sill, and rarely exceed a length of 8 mm. A certain schistosity would seem to indicate that the shearing, which has affected all the Berwyn rocks, was in progress after the sill had cooled and solidified, and many faulted vesicles lend support to this view. Calcite and a soft black substance fill these cavities. One large example showed the latter material enveloping a core of clear calcite; both were surrounded by a layer of ferric oxide, and the whole enclosed in a shell of blue translucent chalcedony.

Under the microscope the rock is hemi-crystalline, with a groundmass consisting chiefly of minute lath-shaped microlites of felspar, many of which are immature or corroded, sometimes with bifid terminations. The structure is trachytic to pilotaxitic, with well-defined flow-orientation. The interstices of the felspar laths are filled with a feebly-polarizing material which has the appearance of a crypto-crystalline devitrification product. In ordinary light this is seen to be of slightly greenish colour and pleochroic. Between crossed-nicols it is resolved into dark fibrous aggregates, and it is thus probably one of the chlorites. True isotropic matter occurs as minute specks and patches which are clear and structureless in transmitted light. In some cases they may be referred with certainty to a zeolite, small nests of analcite having been observed in hand-specimens of the rock.

F e l s p a r s . The narrow laths, averaging 0·2 mm. long by 0·25 mm. wide, are all plagioclase, and on the whole are in fresh condition. They are twinned medially, and extinguish nearly parallel to their length (0° to 4°), indicating an acid oligoclase. Larger phenocrysts up to 0·8 mm. long in size occur very sparingly, and these are also triclinic. They are tabular to columnar in habit, with the twinning-lamellæ only faintly visible. Few of them are perfect, or even clear, and they are usually of skeletal shape, fringed or largely replaced by chlorite, saussurite, or calcite. They are of slightly more basic composition than the microlites, and are referred to the oligoclase-andesine series. Some of the better preserved individuals show a more acid margin than the nucleus.

P y r o x e n e as a constituent is practically of negligible importance, and is the only original ferro-magnesian mineral which can be recognised. It is absent from many sections, but when present it consists chiefly of grains of nearly colourless augite with interference-colours not rising above yellow of the first order. In very rare instances phenocrysts of augite in good condition are met with, ranging in size up to 1·5 mm. long, showing the characteristic cleavage, and polarizing in golden-brown colours.

The a c c e s s o r y minerals are few. Sparse ilmenite, specks of hematite and pyrites, represent the iron-ores; apatite is only rarely present. Chlorite is very abundantly developed, and is intimately associated with secondary quartz, which is also plentiful. Granular epidote and sphene in granules and aggregates are scattered through the rock, the latter being especially characteristic. Calcite is of very common occurrence, as the hand-specimens would indicate, and not only is found disseminated throughout the body of the rock, but also forms the filling of the vesicles which characterise the outer margin of the rock.

In the upper portion of the workings the junction of the igneous intrusion with the slate forms a breccia, and thin sections of the latter show strikingly plagioclase microlites in streams winding around the margins of the brecciated fragments, which have in places a vitreous selvage, colourless to dark brown, and quite isotropic, not to be mistaken for a fine-grained induration of the sedimentary rock.

Dr. Elsden* has described an almost identical rock from Abercastle (North Pembrokeshire), which he named "lime-bostonite" (Brögger), but which Professor Rosenbusch† classed as a keratophyre. Messrs. Cantrill and Thomas‡ record a similar rock from Llangynnog (Carmarthenshire), but do not submit any chemical analyses. This latter rock, which is intrusive into sediments of Lower Arenig age, is built up almost wholly of oligoclase microlites, usually showing single twinning, but of rather better orthophyric habit than those of the Coed-y-Glyn rock, and it is also characterised by pilotaxitic and vesicular structures.

A further close resemblance is furnished by the keratophyres of Skomer Island,§ but in this case the rocks are extrusive, with a less well-marked flow-structure. In other features they are said to be identical in most respects with the "lime-bostonite" of Abercastle.

The Coed-y-Glyn intrusion may accordingly be described as a keratophyre. The chemical composition is given in the analysis hereunder, together with that of other rocks for comparison:—

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* Quart. Journ. Geol. Soc., Vol. lxi, 1905, p. 594.

† "Mikroskopische Physiographie der Massigen Gesteine," 1908, Vol. ii, p. 944.

‡ Quart. Journ. Geol. Soc., Vol. lxii, 1906, p. 240.

§ H. H. Thomas, "The Skomer Volcanic Series (Pembrokeshire),' Q.J.G.S., 1911, Vol. lxvii, pp. 194-5.

		I.	II.	
SiO_2	... ...	52·90	55·38%	
Al_2O_3	... ...	18·94	18·34	
FeO	... ...	9·56	5·86	
Fe_2O_3	... ...	0·12	1·13	
CaO	... ...	3·00	3·25	
MgO	... ...	5·01	3·47	
Na_2O	... ...	6·41	7·12	
K_2O	... ...	0·38	0·22	
H_2O +	... ...	3·04	2·39	(Combined water.)
H_2O −	... ...	0·01	0·48	(110° C.)
CO_2	... ...	0·85	2·00	
P_2O_5	... ...	trace	trace	
TiO_2	... ...	0·02	0·90	
BaO	... ...	nil	—	
FeS_2	... ...	trace	—	
MnO	... ...	nil	—	
		100·24	100·54	

Sp. Gr. = 2·772.

I.—Coed-y-Glyn, Chamber Quarries, Llantsantffraid-glyn-Ceiriog, N.W., analysis H. W. Greenwood.

II.—"Lime-Bostonite," Abercastle-Mathry district (Pembrokeshire), analysis J. V. Elsden, D.Sc., F.G.S. Q.J.G.S., Vol. lxi, p. 595.

C.B.T.

(2) Hirnant Complex.

This complicated series is affected by a system of cross-faulting which contributes to the difficulty of the elucidation of the actual structure. The majority of the faults are apparent in the field, but others must exist in connection with the scheme of repetition by folding if the complex as a whole is to be satisfactorily explained.

The two blocks of beds mapped "ash" are independently bounded on all sides by faults of high inclination, and are further bisected within their area by what appears to be a system of minor thrust-planes rather than normal faults. Apparently five in number, the igneous bands, indicated by massive disjointed exposures, are isolated from the surrounding country and, together with their interbedded sedimentaries, dip in opposite directions at angles ranging from 5° to 85°. There are no traces of connecting links in the dividing valley between Craig-ddu and Cyrniau, but loose blocks are occasionally turned up from the deeply cultivated land. The late Mr. Cope gave much attention to this difficult area, and his opinions are summarised in the following extracts from his note-books:—

"It is probable that the complex lies approximately in its "original position, but the whole block has been turned about on an "E.-W. axis, the eastern portion of the area coming to rest with "the strata nearly vertical, whilst the western part dips as low as "at 5°. Stratigraphically, it must lie near the horizon of the "Carnedd-y-Ci intrusion and low in the order of succession. The "longer the locality is examined the more the broken-up nature "of the small area becomes revealed, more so than would appear on "the surface. It is also clear that any repetition of the sheets by "folding occurred before the N.-S. faults separated the two blocks. "Correlation of exposures is not a simple matter, and it may be "that two main intrusive sheets will be found sufficient to account "for many of the outcrops on the hillsides.

"There are no 'ashes,' and the rocks possess no affinity with those "of the Peripheral Tuffs series. That they are intrusive admits of "no doubt, as the examination of various localities proves, but "neither chemically nor petrographically are they related to the "acid lavas of Llangynnog. In the quarry East of Bache-doethion "(Cyrniau) the overlying grits are hardened and baked. On "Carnedd Ilog portions of the higher band penetrate the slate "with bulbous and finger-like processes, partially absorbing it, while "near the base of Craig-ddu, at the mine-adit, are clear examples of "connected intrusive veins which are more dense and felsitic than "the main sheets, and are flinty on the edges, with usually a band "of pyrites. On the other hand, the worked slate beds between "the upper and lower main igneous sheets of Craig-ddu are not "sensibly altered, even at the contact with the strongly columnar "igneous rock."

The rocks have so much in common that a general macroscopic description will include the leading features. The mineralogical composition is fairly uniform, the principal difference being variations in texture.

Hand-specimens are pale grey to greenish-grey, close-grained, dull in appearance, relieved by a few glistening felspars, and in the field there is a general resemblance to the light-coloured types of the Carnedd-y-Ci series. The rocks are tough but not very hard, and they break with an uneven fracture on which acid tests give a slight reaction. A polished surface reveals a confused arrangement of elongated felspars, turbid and yellow, set in a greenish felsitic matrix. The mean specific gravity is 2·783.

Although Mr. Cope speaks of rocks collected from 23 localities having been sliced, less than half of these slides were found in his collection, and it is from these only that the following microscopic descriptions have been compiled after examination.

The felspars are all triclinic, and largely predominate over other constituents, thus giving rise to the pale colour of the rocks. There is sometimes an approach to ophitic structure, but in other instances the rock is seen to be hemi-crystalline with an originally glassy base, and a residual one which is now mainly felsitic.

The felspars exhibit a confused arrangement of grouping and structure to which no one particular descriptive term appears applicable. Long narrow plates, acicular prisms, and thin sinuous forms, occur with microlitic areas in which minute laths are imperfect and often without regular form. Sheave-like bundles, twisted and bent, and groups of slender bifid crystals radial from a point, also stellate and cruciform groups, are included among the types of growth. A variolitic structure is also observed in which a black cross is sometimes visible between crossed-nicols. A definite orientation in the arrangement of the felspar laths is rare, although in the more finely textured specimens taken from contact-surfaces a certain flow-structure is at times shown by the microlites.

Twinning is usually simple on the albite-law, with few indications of lamellar striations. Many of the felspars are in a stage of fairly advanced decay, a large proportion being pseudomorphs. Secondary products are frequently alone responsible for the bright polarisation tints of many individuals. The extinction-angles show the plagioclase to be of the oligoclase-andesine series.

The ferro-magnesian minerals are only represented by either fibrous or granular chlorite, filling the interstices between the felspars, or by pseudomorphs of sub-ophitic and idiomorphic augite. In the latter case octagonal cross-sections give the interfacial angle of 87°. None of the original augite remains, and it has been replaced by a pale-brown crypto-crystalline material, secondary calcite and chlorite.

Associated with the interstitial chloritic areas is much indeterminable matter which appears to be an admixture of carbonates, zeolites, and kaolin.

Accessory minerals are of no particular importance, and include ilmenite, zircon, pyrites, apatite, and magnetite in small quantity.

Secondary minerals. Calcite is rare in some slices and very abundant in others. It occurs in strings or as pseudomorphs. Polished surfaces etched by hot acid show the great extent of replacement by carbonates which has taken place in specimens from certain sections. Leucoxene shows, as usual, a large development, either as grains or small perfect skeletal forms. Hematite occurs as blood-red specks, but is mostly altered into limonite. Zeolites in drusy cavities are represented by natrolite, analcite, and prehnite (?), a few radial groups representing the characters of the latter.

An interesting type is furnished by several specimens (178, 179, 188) from the outcrop which is represented as a roughly "Y"-shaped band, marked "Fs," near the South-east corner of the One-inch Geological Survey Map (sheet 74 S.W.). This band is shown as running along the slopes of Craig-ddu and Carnedd Ilog, North of the village of Hirnant, and the particular specimens were taken close to the lode near Velin cwm-wr, as well as from the band touching Pentre-uchaf farm, about $\frac{1}{4}$ mile East of Pen-y-bont fawr.

Under the microscope these rocks are seen to consist almost wholly of plagioclase felspars of the oligoclase-andesine series, with originally subordinate pyroxene. The felspars occur in three principal habits, (*a*) long acicular prisms, either twinned on the albite-law or showing only simple twinning, (*b*) broad tabular crystals with albite and Carlsbad twinning, occasionally also untwinned, (*c*) microlites, both twinned and untwinned, giving rectangular and quadratic sections. The felspars are fresh on the whole, but at times have a core of chloritic and sericitic material. Crystals of the first-mentioned habit predominate, averaging 0·35 mm. in length by 0·075 mm. in width, with a maximum size of 1·5 mm. long by 0·1 mm. wide. They occure in stellate groups and sub-parallel arrangement. No original ferro-magnesian minerals are preserved, and the interstices between the felspar laths are occupied almost wholly by chlorite, associated with a little calcite and secondary quartz. This fibrous chlorite is nearly colourless, occasionally showing a very faint tinge of green, and between crossed-nicols it polarises in weak colours. Ilmenite is not common; leucoxene and hematite are abundant as secondary developments. The structure varies from variolitic to insertal, resembling that shown by certain tholeiites, but no definite trace of the undoubtedly original glassy base remains.

For this pale greyish-yellow trachytic-looking rock a suitable type-name is not easy to find among the members of the hypabyssal group. The silica percentage brings it into the intermediate class, but it does not correspond exactly with any of these types. It agrees in certain respects with the Coed-y-Glyn rock, but on the other hand there are marked differences of colour, texture and structure. It is apparently purely local in occurrence, and, according to Mr. Cope, does not occur elsewhere in the Berwyn area as far as he had discovered. Dr. H. H. Thomas, who kindly examined the slides, informs me that he has not met with a similar rock nor read any description of any type corresponding to it.

In his opinion "it might well belong to an acid Na-rich end of the tholeiite series." Under the circumstances I propose to designate this type by the name "Hirnantite" unless future investigations enable it to be classed otherwise. The chemical composition of this rock (Pl. II, fig. 1) is shown in the following analysis by Mr. H. W. Greenwood:—

SiO_2	58·90%
Al_2O_3	20·61
FeO	8·03
Fe_2O_3	0·23
CaO	trace
MgO	nil
Na_2O	6·78
K_2O	0·38
H_2O + ...	2·35
H_2O −	0·60
CO_2	nil
P_2O_5	trace
TiO_2...	2·36
BaO	trace
FeS_2...	nil
MnO	nil
	100.24

Sp. Gr. = 2·728.

The tongue of rock intruded into the slate at the mine adit-level on Craig-ddu is sufficiently interesting to warrant a few notes.

The invading vein is only of small dimensions, and shows grey porcellanite at the contact with the slate into which it merges with evidence of fusion. The offshoot cooled more quickly than the main mass, and presents all the characters of a glassy selvage. It may be termed a fine-grained variolite (Pl. II, fig. 2). A line of pyrites cubes down the middle of the vein indicates an apparent last effort at segregation. It is evident that the slate has been subjected to severe dynamic pressure as the false-cleavage, crushing, and minor faulting testify. The specific gravity at the contact is 2·71 as compared with 2·66 some 50 yards away. Slices cut from the centre of the intrusive vein outwards through the contact-edge into the slate show under the microscope the following phases in close gradation.

Igneous rock:

(*a*) A felted groundmass of felspar microlites, stellar and sporadic groups showing a tendency to variolitic structure : interstitial matter pale coloured, indeterminate.
(*b*) The same but of closer texture, transmitting less light. The sheaf-like structure is well shown.
(*c*) Micro-felsitic, very dark, some isolated microlites.
(*d*) Brown, compact, no microlites : practically isotropic.
(*e*) A black isotropic border sharply defined, fused with slate in places.

Slate:

(*f*) Dark grey colour, non-polarising, structureless material with minute points of light, possibly quartz.
(*g*) Slightly more granular, passing into (*h*) a compact structureless argillite.

C. B. T.

G. The Intrusive Basic Rocks.

(1) Pen-y-Bont (Hendre) Sill.

The Hendre Quarry on the denuded valley-wall exhibits this sill in great perfection of detail and completeness of structure, and proves unquestionably its intrusive nature. This sheet may well serve as a general type of all the other basic sills to be described in its mode of occurrence, and as there is reason to assume a relationship regarding origin, habit, and age of intrusion, it will avoid repetition if, in describing the Hendre rocks, deviations from the normal characters in the case of the other intrusions are alluded to in proper sequence.

The true thickness of the sheet as exposed in the quarry is 96 feet, but it exhibits considerable variation, and at Treceiriog it is not more than 32 feet; it appears probable that throughout the whole length of the strike its maximum thickness would not exceed the former figure.

Mr. C. C. Moore, F.I.C., in an exhaustive paper,* has dealt with the chemical and physical properties both of the intrusive rock and the sediments in contact.

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* "The Study of the Volume Composition of Rocks." Part II, "The Examination of an Igneous Intrusion." Proc. L'pool Geol. Soc., Vol. ix, pp. 247-283.

The associated beds are of Ordovician age and consist of dull grey types of fine grits and shaley slates dipping at 16° N. 22° E., less steeply than the increasingly higher angles in the Ceiriog valley would lead one to suspect.

The igneous rock has been forced along bedding-planes on, or very near, the horizon of the dark shales of the Cader Berwyn series, and the same relations between the shales and the sills exist both in the Cader Berwyn and the Pen-y-Bont districts.

The thickness of the altered slate is given by Moore as approximately 100 feet on each margin, but the actual thickness in which chemical change and induration is observed in the field is only 2 or 3 feet. On the upper margin there is a gradual transition from the unaltered slate through progressively altered bands; near the contact the rock, at first characterised by an incipient chiastolization, becomes a solid, intensely hard mud-stone. The line of junction with the injected rock is rough and irregular, the molten magma having in some places removed and incorporated much of the slate, or in others floated off large fragments. Porcellanization is of frequent occurrence. The changes in the lower margin are not quite the same. Here the alteration-zone is somewhat deeper, the line of demarcation is more confused, at times barely definable, and there is less development of chiastolite. Near the contact fragments of altered white slate, red felsite,* and blocks of bleached dolerite are included in the sill, indicating some brecciation of the lower surface. A familiar feature of the intrusive rock is the gradation in density of grain from the chilled edge, the marginal fine basaltic texture becoming coarser inwards until in the middle of the mass the rock has the appearance of a coarsely grained gabbro. Every variety of typical doleritic rock can be traced throughout the

* See Cwm Clwyd, Tuff Series III.

thickness of the sheet, and on the open quarry face all stages in the process of change can be followed even into the last phase of massive serpentine. The regular columnar structure which was developed has been much disturbed by later earth-stresses.

In hand-specimens the Hendre rock is mostly of a sombre greenish-grey colour, nearing yellow as decay advances, and becoming lighter in colour towards the centre of the quarry where chemical substitution of minerals has advanced far, the changes resulting eventually in the production of a mottled green and yellow serpentine as homogeneous and as soft as the altered intrusions of Anglesea.

In its more coarsely crystalline portions the rock is holocrystalline, and more granular than ophitic. Felspar and pyroxene are the chief constituents; in the more rapidly cooled portions the former mineral has a blade-like habit, and in the parts last to consolidate they form rough patches and segregated groups. In hand-specimens the felspars are often glassy; pyroxene has mostly a diallagic lustre. Green or yellow epidote is abundant. A striking variety has a pink decomposition-matrix in which are set large dark-green pyroxenic plates, and there is a pseudo-vesicular structure. Skeletal shapes of felspar are large but turbid.

A type with low specific gravity (2·645) shows almost complete substitution of the minerals rich in iron and magnesium by the lighter silicates, its tint of greyish-yellow, unrelieved by the darker minerals, suggesting the final passage into serpentine. Veins of calcite, chalybite, and dull-green fibrous epidote, traverse the quarry-face. The latter mineral is also present in colourless form in conjunction with a little pink tremolite, and has crystallised in long prisms on the walls of cavities, the interstices of the rock having subsequently become filled with quartz, spathic iron, and radial zeolites. Pectolite in botryoidal masses, and apophylite in small colourless prisms, have also been found.*

Thin sections, although generally very turbid, show the rock to have been originally a holocrystalline member of the dolerite family, composed of lime-soda felspars, pyroxene, ilmenite, and magnetite, with a structure varying from sub-ophitic to ophitic.

F e l s p a r s . The felspars, which were the first of the principal minerals to crystallize out, and upon which the pyroxene was moulded, show considerable diversity of habit and structure. Many large tabular crystals, either simple individuals or binary twins, have the appearance of orthoclase, but straight extinction in the zone 100 : 001, and the absence of symmetrical extinction with reference to the composition-plane in the binary twins, show that they belong to the triclinic series. Plagioclase was much in excess of pyroxene, the calculated proportions being about 7 : 2. In the same slides all stages of preservation of the plagioclase can be observed, from fresh clear crystals to others which, still retaining their rectangular shape, consist wholly of decomposition products.

Some of the larger phenocrysts have been converted into a reticulated mass of secondary products with an irregular increase of volume, and consequently disturbed polarization, but at the point of contact with recognisable pyroxene the edges of the felspar, fringed at times with a narrow reaction-rim, are frequently pellucid and sharp, possibly of more acid composition. Dr. H. H. Thomas, in the last "Summary of Progress of the Geological Survey," refers to this rock as "albitized," and has pointed out to the writer, after examination of some typical slides of the Cope collection, how many of the larger basic felspars are zoned and traversed by fine strings of secondary albite. In many cases the process

* "Summary of Progress of Geological Survey for 1913" (1914), p. 77.

of albitization is well advanced, and often where phenocrysts are zoned the central portions of the original basic material have been replaced by albite, leaving the more acid narrow borders. In some cases where molecular replacement of the original twinning-lamellæ has taken place, the extinction-angles of albite are given. The phenocrysts are columnar to tabular in habit on the whole, and occasionally a porphyritic tendency manifests itself in the greater extension of the "*a*" axis. Some large phenocrysts have the medial line of simple twins, but in many instances there is no twinning, and complete extinction takes place. The short stout prisms show multiple twinning, but there are other crystals long and narrow in habit, usually found in rudely stellate groups, which have a simple plane of composition, and give oblique extinction. Lastly, there are abundant microlites of a later generation, of the same composition as the more dominant type, which occur in groups. The extinction-angles determined in thin sections and cleavage flakes indicate the predominance of the andesine-labradorite series. In a few instances in which the extinction on brachypinacoidal flakes could not be clearly established, the cleavage was noted as being approximately at right angles to the positive bisectrix. Oligoclase possibly occurs in conjunction with the more basic type as marginal zones. Extinctions referred to the length of the microlites gave 12° to 20°.

Zoning is well shown, but the inner basic zones rarely show the bounding-planes so distinctly as the outer acid zones whose margins are comparatively free from magmatic corrosion.

P y r o x e n e . This is represented by augite which is fresh on the whole. In transmitted light it is pale-brown, and between crossed-nicols it shows bright interference-colours. At times partly idiomorphic, it occurs mostly as large plates moulded on the plagioclase, with sub-ophitic to ophitic structure. The prismatic and pinacoidal cleavages are well defined, and orthopinacoidal twinning and zonal structure are to be observed occasionally. Examination by convergent light of sections from the zone 100: 001, in a direction parallel to 100, shows a somewhat oblique optic axis; with longitudinal sections the straight extinction, with the trace of an axial shadow, is conclusive. Some of the large ophitic plates are fissured, and a fibrous or scaly viriditic decomposition product is noticed along the cracks. The augite at times disappears before the felspar, and its borders are traceable by granules of chlorite and magnetite. In the advanced stages of alteration it is represented by scattered dark granular masses of chloritoid minerals. At other times, just before the stage of conversion into amorphous serpentine, some slices show the development of zeolitic material. Inclusions of apatite, mica, magnetite, and pyrites are numerous.

A c c e s s o r y minerals are but few. Apatite is of rare occurrence as slender prisms. Ilmenite is common as grains, skeleton-crystals, and hexagonal plates, and alters into leucoxene. Magnetite, which is not plentiful as a primary constituent, occurs chiefly as dust or minute octahedra, although larger forms, characterised by regular contours, are present. Zircon in minute prisms is sparsely distributed, and this remark also applies to sphene, of which only a few examples were noted, derived probably from ilmenite.

S e c o n d a r y minerals. Pyrites occur in abundance in small cubes and granules, together with pyrrhotine and chalcopyrite. Magnetite is present as scattered dust and granules bordering altered augite crystals. Acid tests on uncovered sections were necessary at times to discriminate between this mineral and unaltered ilmenite. Anatase occurs rarely as slightly dichroic granules of pale-brown colour, greenish-yellow in transmitted light. It is associated with sphene, and doubtless arises from ilmenite. Biotite in small flakes is unimportant. In some sections epidote is present in great abundance, and is associated with a little zoisite and saussurite. Under the microscope it is granular to prismatic, with high refraction and birefringence. Quartz is infrequent, occurring as small stringers and in shapeless areas moulded on other minerals. It is clearly of late origin. Secondary albite occurs in interstices to a slight extent.

Finally there is a small group of minerals which at times constitute almost the bulk of the rock. These are interesting as representing the breaking down of some of the primary minerals which they occasionally replace. They consist of zeolites, carbonates, saussurite, chlorite, and serpentine.

Zeolite group. Slices cut from specimens from all parts of the quarry show in abundance a mineral which is undoubtedly analcite. It occurs in irregularly shaped areas, as well as in the angular interstices between other constituents. It is colourless and transparent, showing at times a rectangular cleavage. Between crossed-nicols it is generally isotropic, although anomalous double-refraction in low tints is also to be observed. From the way it has eaten into the adjacent minerals, shreds of which it frequently encloses, it is clearly of later origin than the plagioclase and augite. There does not appear to be any ground for regarding it as other than secondary. There is nothing to indicate the former presence of nepheline in the Hendre rock, and the predominant felspars are generally of basic composition; but, on the other hand, the presence of the secondary albite points to the subsequent introduction of soda into the rock, and the analcite is probably connected with the process of albitization, although at a somewhat later period. Natrolite occurs in radiate fibrous bundles and fan-like aggregates shown in beautiful examples on the walls of cavities. Little fans radiating from the felspars indicate the source of origin. The fibres are roughly truncated, and show bright polarisation colours, with straight extinction. Sometimes the radial masses show an interference-cross.

Carbonate group. The carbonates of lime, iron and magnesium play a considerable part in masking the original minerals or as pseudomorphs.

Calcite is present in particles or massive form. It transgresses the borders of felspars previously displaced, and works along cleavage-planes, splitting up in the course of time the minerals which it invades.

Chalybite. A brown ferrous carbonate, seen in patches in hand-specimens, behaves like the lime-carbonate. It is found within areas previously occupied by pyroxene, and is associated with granular magnetite.

Magnesite is less common, and is derived from the residue of the decomposing pyroxene. It has been noted as large whitish patches, somewhat opaque, in pale-green serpentine.

Saussurite. This variable and complex mineral is the only representative of the felspar in many slices, although, on the other hand, it may be observed in contact with clear felspars.

Chlorite, in this case a decomposition-product of pyroxene, is present in great abundance. It is structureless in ordinary light, with pale-green tints. Between crossed-nicols several forms are noticed, scaly or fibrous aggregates, showing an interference-cross, being most common. The areas of development are large and irregular, and from their border filamentous processes project. Pleochroism and birefringence are weak.

Serpentine. This mineral represents a further stage in the disintegration of the augite. It sometimes forms pseudomorphs by replacement, and, like chlorite, sends out filiform processes. In ordinary light the colour varies from pale yellow-green to olive-green in the amorphous form, but there are a few examples of radial tufts and hair-like veins, yellow in transmitted light, which are referred to true chrysotile.

I append analyses of the rocks of this sill, together with a few others for comparison:—

		I.	II.	III.	IV.	V.
SiO_2	...	46·12	47·88	45·73	46·30	51·22
TiO_2	...	0·16	0·18	0·18	0·18	2·42
FeO	...	8·49	6·53	8·86	8·05	8·73
Fe_2O_3	...	4·66	3·73	4·81	4·44	4·32
Fe_2S_3	...	0·60	0·69	0·62	0·64	0·49
Al_2O_3	...	13·43	13·64	14·22	13·99	14·06
CaO	...	9·95	12·42	10·16	10·88	8·33
MnO	...	—	—	—	—	0·16
MgO	...	7·06	8·64	8·23	8·34	4·42
Na_2O	...	2·27	2·15	2·26	2·21	2·55
K_2O	...	0·46	0·44	0·45	0·45	1·25
CO_2	...	4·11	1·07	1·01	1·34	0·19
H_2O	...	2·69	2·63	3·47	3·18	1·28
P_2O_5	...	—	—	—	—	0·25
		100·00	100·00	100·00	100·00	99·67
Sp. Gr.	...	2·82	2·91	2·85	—	2·98

I.—Hendre Quarry, Glyn-Ceiriog, Llantsaintffraid, D.C. One foot from upper junction of sill with slate.
II.—Ditto. Middle of the intrusive sill.
III.—Ditto. Two feet from the lower edge of slate contact.
IV.—Mean calculated composition of the intrusive mass.
Anal. C. C. Moore, F.I.C., Proc. Liverpool Geol. Soc., 1902-3, Vol. ix, pp. 279 and 283.
V.—Dolerite without olivine. "Whin Sill," Durham. J. J. H. Teall, Quart. Journ. Geol. Soc., Vol. xl, p. 654.

C.B.T.

(2) Cader Berwyn and Llyn-Llyn-Caws Sills.

The well-known Craig Berwyn affords a fine natural section of the upper sill. From where the North Carnedd-y-Ci fault cuts it out on the East the dark band of rock can be seen to traverse obliquely the whole breadth of the cliff-face in a bold precipitous exposure. Where the watershed is crossed the northerly dip conforms to the slope of the ground, and the outcrop becomes obscured. Near the southern extremity the sill probably thins out, but from Cerig-duen onwards there are indications which suggest continuity as far as the Bryn-mawr fault.

The Llyn-Llyn-Caws lower sill has a similar South-west trend. Near the fault in Blaen Iwrch it is pierced by an adit to a slate-mine which proved the thickness to be 48 feet. As in the case of the upper sill, the relations can be best studied in a dip-escarpment, where it is seen as a dark-coloured band encircling the upper rim of the Llyn-Llyn-Caws cirque. For a distance of about a mile the outcrop is obscured, and in Cwm Rhiwiau it is inferred by the presence of spotted slate yielding incipient chiastolite. From Disgynfa traces occur as far as the Bryn Mawr fault, where the sill terminates as an isolated feature above Cwm glan yr afon. A marked induration of the sedimentary rocks is observable in visible contacts. No dykes are apparent, but at times processes pierce the slate which then has been absorbed or floated off in lenticles.

The rock constituting these two sills is bright in colour, shades of grey and pale-green predominating, and the component minerals exhibit no strong contrast. Although generally of granular texture, exceptions may be cited in specimens from the lower sill which are fine-grained, of darker colour, and slightly fissile, and from the summit of Cader Berwyn, where the rock is of a bright yellow colour through epidotisation, showing a smoke-coloured felspar and ophitic plates of pyroxene pale-brown to pink in colour.

The microscopic examination shows the following features:—

F e l s p a r s. These do not differ much from those of the Pen-y-Bont sill, a noticeable exception being those present in a small unmapped sill in Cwm-Blawd-du where the type is basaltic. Some broad tabular forms, containing schiller-plates and many inclusions, appear clear and fresh, although side by side with crystals in a saussuritic condition.

P y r o x e n e. Augite has been an important constituent, as the remains of large ophitic plates testify. It still exists in quantity, although much decomposed, and is mostly brownish-pink in thin section. The two cleavages in sections perpendicular to the prismatic zone are frequently good, and others of the diallagic type with parallel striations are also prominent. Small structureless ragged plates with weak relief and low interference-colours suggest a rhombic pyroxene.

A m p h i b o l e. A little hornblende with faint pleochroism is scattered through some of the slides, and is apparently a secondary growth on the augite.

A c c e s s o r y M i n e r a l s. These include apatite in short prisms, sometimes curved: Ilmenite in large plates in all stages of alteration to leucoxene. Some indeterminate masses in association, semi-translucent, brown in colour, may be sphene which is also recognizable in its typical form. Zircon is but rarely seen, and only a few minute octahedral crystals of magetite are present.

S e c o n d a r y M i n e r a l s. Pyrites and magnetite are unimportant. Epidote occurs in some of the Cader Berwyn specimens in abundance (108a) but otherwise is not generally plentiful. Calcite is mostly pseudomorphous, or forms a confused matrix, sometimes occupying fairly large areas.

Quartz occurs interstitially. Chlorite in massive and fibrous form is present in large areas. Serpentine occurs in the same manner as in the Pen-y-Bont rock.

Analcite is the only zeolite observed, and occurs in a few slides as small patches, water-clear, with indefinite boundaries. A large proportion of it is isotropic, but when otherwise the birefringence is weak as usual.

In the same series a yellow-coloured rock (slide 108a), taken from the vertical columns of Cader Berwyn, deserves special mention. Between crossed-nicols thin sections of this rock have a very beautiful appearance.

The felspars, formerly in large plates, have nearly disappeared, having been largely replaced by granular epidote. This process of replacement can be clearly traced, but there is no pseudomorphism, merely an infilling of broken prismatic forms. Felspar appears to have been always subordinate to the ferro-magnesian minerals, approximately in the ratio of 1:5. The latter are represented by large plates of pale augite and a few small plates of what looks like original hornblende. In these the principal cleavages are nearly parallel so that the most noticeable sections are cut in the zone of the vertical axis. There are traces of what may be a rhombic pyroxene. A remarkable feature is the development of secondary quartz which behaves often like an original constituent. It does not form a granular mosaic, as is so frequently seen, but is moulded clear and colourless with considerable sharpness of outline on the other minerals. Its period of formation is proved by inclusions of epidote, and where the pyroxene has become split up into lath-like fragments they are often embedded in the quartz. A number of tests of specimens from various points on the strike gave an average of 2·786 sp. gr., the yellow rock with the excess of epidote giving 3·11 sp. gr.

The rock comes into line with others of the group as an altered diabase, or hornblende-dolerite at times.

C. B. T.

(3) Carnedd-y-Ci Intrusions.

The hill indicated by this name, lying to the North-west of the main ridge of the Berwyns, would appear from the 1″ map and the horizontal section, No. 35, to be of simple structure. In the Survey memoir it is referred to as "The third mass of contemporaneous interstratified igneous rocks" (of the region). According to Jukes' description quoted by Ramsay,* it is

* "The Geology of North Wales," 1866, p. 216; 2nd ed. 1881, p. 294.

"A peculiar rock resting on a thick mass of dark greenstone: "the pale greenish-grey rock is believed to be a 'greenstone ash' in "contradistinction to a 'felstone ash.'

Jevons,* in the only paper since dealing with this area, assumed a succession of Quartz-keratophyre tuffs, with a lava of the same composition at their base, and the latter is declared to be intrusive.

In the early part of the present paper the late author states that the Carnedd-y-Ci intrusion may be resolved into "a single band of a somewhat unusual type of rock," without any association of tuffs.

The sheet is but of slight thickness, although it presents a broad outcrop in the field. The dip and slope of the ground coincide, and the cover of peat permits of few exposures. In Clochnant the line of fault exposes a coarse dolerite nearly in contact with Bala slates on the Fronwen side. In Cwm Dywyll the outcrop is clearer, and from thence to the valley of Ysgeriau a wide expanse of loose blocks indicates the position of the sill.

"The structural key is found on ascending the low hill to the "N.W. in a low dip-escarpment, nowhere more than 20 feet high, "which extends for about half-a-mile. The true dip is seen to be "about 30° N.W., or 10° greater than that of the outer and higher "beds.—(T. H. C.).

In explanation of the author's views it will not be out of place to quote briefly a few extracts from his field-notes.

"(*a*) There does not appear to be evidence of either pyroclastic "or extrusive volcanic rock in the group, and in most places the "'lava' is directly overlain by an indurated chiastolite-slate. The "sheet mapped as 'greenstone' is intrusive, and abundant proof is "afforded where the sedimentary beds are constantly pierced by the "igneous rock and altered to the point of porcellanization. Higher "in the series, and in contact with the basic intrusion, lie spotted "slates mapped as 'Felspathic trap' and coloured as 'Ashes.' "These beds are only a few feet thick, and certainly bear some "resemblance to a decomposed flaky tuff. The slates below in "contact are strongly spotted, chiastolite being conspicuous as a "product of thermo-metamorphism. A talus obscures the true "thickness of the sill which may be approximately reckoned as 30 "feet."

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*H. S. Jevons. "The Keratophyres of the Breidden and Berwyn Hills." Geol. Mag., Vol. xi, dec. v, p. 14.

"(*b*) I could find no evidence of tuffs, nor indeed of any rocks "which in the field might be classified as such, but the sill, when "carrying much calcite, has a tendency to break up easily under "weathering, and has been brecciated and cleaved by earth in "movements after injection."

"(*c*) At the North-eastern faulted end the Carnedd-y-Ci rock of "doleritic facies passes without visible transition into a true "gabbroidal dolerite."

"(*d*) At the East end of the Carnedd-y-Ci complex the "'keratophyre' of Jevons apparently merges into normal dolerite "at the foot of Cader Fronwen."

(*e*) Sequence of Carnedd-y-Ci group:—

(In descending order: no thickness stated).

Soil and sub-soil.

1. Chiastolite-slate.
2. Spotted slate.
3. Grit.
4. Baked Slate (contact).
5. "Keratophyre."
6. "Greywacke."
7. Micaceous Slate.
8. Chiastolite-slate.
9. Bala Slates. (On Y Foel Fawr.)

His last field-record (April, 1911) is:—"No dark greenstone (of Ramsay) underlies. Definite normal dolerite at North end." "Where brown and granulated it might be taken for ash."

It is clear from these extracts that in the late author's opinion there was only one intrusion which he regarded as being of doleritic nature. The writer has unfortunately been unable yet to examine the field-relations himself, but from the microscopic examination of specimens in the Cope collection it would appear that there are two types of igneous intrusive rocks which build up Carnedd-y-Ci. It is difficult to decide from the author's notes whether this is really a case of a composite intrusion or not. In one entry he refers to "the passage of the keratophyre into normal dolerite," which would appear to be conclusive, although it is not clear whether there is a vertical or lateral gradation. On the other hand a specimen of a soft greenish mudstone (the

"Micaceous Slate," No. 7, of the sequence given) is labelled "lying between the greenstone and felsite." This rock is seen under the microscope to be a typical mudstone, and shows no trace of any thermo-metamorphism. In the absence of an opportunity up to the present for the writer to examine the ground personally, it must be left for future investigation to settle the question whether it is a genuine case of a composite intrusion or not. The two rock-types will be described separately hereunder.

Hand-specimens of the light-coloured rock from the South end of the summit of Carnedd-y-Ci, near the road and quarry, are uniformly of light-grey colour when fresh, yellowish-green when weathered. The rock is of fine texture, breaks with an irregular fracture, and effervesces with H.Cl. The mineral components visible under the lens are small clear felspars, greenish wisps of chlorite, patches of calcite, and minute dark grains which, on extraction from the powdered rock by the magnet, prove to be magnetite.

Under the microscope the rock is seen to be composed of felspar phenocrysts set in a groundmass mostly consisting of allotriomorphic granular quartz, felspar microlites, interstitial chlorite, and calcite, with a tendency to insertal structure where best developed.

The felspar, which is in fresh condition generally, occurs mostly as slender microlites, averaging 0·15 mm. long by 0·02 mm. wide, either untwinned or only showing single twinning. Broader lathy forms, averaging 0·5 mm. long by 0·04 mm. wide, are also abundant, and exhibit twinning on the Carlsbad and albite laws. Larger phenocrysts of tabular habit, about 1·5 mm. long by 1·0 mm. wide, are more rarely present. The acicular microlites of the matrix extinguish at 0° to 4°, while the laths and phenocrysts give symmetrical extinctions of about 16°, indicating oligoclase and albite felspars.

Quartz is present as an original constituent in allotriomorphic granules abundant throughout the groundmass. In secondary form it occurs in strings, granules, and bi-pyramidal prisms and basal sections closely associated with the calcite by which it is frequently enveloped.

Ferro-magnesian minerals are not present in recognisable condition as original constituents, being only represented by chlorite in the interstices between the felspar; it has doubtless been derived from original pyroxene.

The accessory minerals comprise magnetite, ilmenite, and a little apatite. Among the secondary products calcite comes in importance after the chlorite and quartz, occurring as plates and flakes showing cleavage-traces and bright interference-colours. Granular sphene is abundantly scattered throughout the rock, and is particularly characteristic.

The chemical composition of the rock is shown by the following analysis by H. W. Greenwood of a specimen from the South end of the summit of the hill:—

	%
SiO_2	49·52
Al_2O_3	15·86
Fe_2O_3	0·75
FeO	3·85
MgO	3·40
CaO	12·39
Na_2O	3·08
K_2O	0·25
H_2O +	1·20
H_2O −	0·90
CO_2	8·77
P_2O_5	0·02
TiO_2	0·20
MnO	0·02
BaO	nil
SrO	0·01
	100·22

Sp. Gr. = 2·726.

It will be seen from the foregoing description and analysis that the light-coloured portion of the Carnedd-y-Ci mass consists of a rock of basic composition, characterised by original albite felspar and quartz, much decomposed as regards original femic constituents, and rich in carbonates. While the silica content is much lower than is generally the case with the keratophyres, there can be no question as to the primary nature of much of the quartz, and this must be taken into consideration in its name. The rock thus appears to come more under the head of quartz-keratophyre, although not effusive as required by Rosenbusch, and Dr. Thomas, who has examined the slides, concurs in this designation.

I am not sure whether this is the same rock as that to which Jevons alluded by the same name from the same locality, as he described therein the presence of diopside which, however, has not been found by the writer in identifiable condition, although this mineral undoubtedly occurs in the doleritic type with which the quartz-keratophyre is associated.

The more typically doleritic rock is variable in texture, being denser on the upper margin than in the coarsely crystalline central portions. When fine-grained it is speckled with light felspar, dark pyroxene, and blebs of calcite; at other times it is very coarsely crystalline, mottled grey, green, and black with large phenocrysts of plagioclase, chloritic aggregates, and plates of pyroxene. A slight reaction with acid is shown by some of the hand-specimens.

Thin sections show that structurally the rock is sub-ophitic to ophitic, with a preponderance of felspar over ferro-magnesian minerals, except in the very ophitic portions. The felspars consist mostly of phenocrysts of columnar and tabular habit and small lath-shaped microlites. In a few instances there are also present platy aggregates, with rather indefinite boundaries, showing irregular polarization, and apparently component parts of a whole. Alteration-products have largely obliterated the freshness and clearness of these platy areas, but occasionally the original clearness of portions is observable, and the refractive index is then seen to be less than that of balsam. Though frequently decomposed and turbid, the felspars on the whole may be said to be in good condition. Twinning on the albite and Carlsbad laws is common, and one or two examples of the Baveno law were noted. The albite-type predominates in small well-formed phenocrysts. Cleavage is more distinct in the larger individuals. A long series of measurements with cleavage-flakes and on individuals in thin sections indicated the plagioclase to be mostly albite. This was confirmed by supplementary tests; the flame-test with cleavage-flakes gave a strong continuous soda colouration, and the specific gravity of a number of clean fragments of phenocrysts was found to be nearly 2·63.

Of the pyroxene group a monoclinic member is present in abundance in granular and often idiomorphic form showing prismatic cleavages. When least altered, and then chiefly occurring as undecomposed cores, it is either colourless or has a faint pinkish tinge. The interference-colours are high in the second order, and the extinction-angles range from 36° to 50° on vertical sections. Many of the grains extinguish simultaneously over fairly wide areas, and are thus optically continuous, but the structure is much obscured by the abundant development of calcite. The mineral may be referred to the monoclinic group, the colourless type being doubtless diopside, and the other variety augite. It is evident that a far larger proportion of pyroxene existed formerly, but has been mostly replaced by calcitic and chloritic products. The presence of a member of the rhombic pyroxene group is indicated by pseudomorphs of bastite in elongated forms, pale-yellow to light-green in ordinary light; between crossed-nicols the interference-tints are weak, and extinction, when noted, takes place parallel to the fibres of longitudinal sections. It has probably been enstatite.

Accessory and secondary minerals are few in number, and consist of magnetite, ilmenite, abundant chlorite enveloping the felspars and the augite-cores, sphene, abundant calcite and quartz, with epidote rarely. The rock is thus an albite-diabase.

The occurrence of these two types of intrusive igneous rocks in the Carnedd-y-Ci mass provides another example of the association, not hitherto recorded in North Wales to my knowledge, of quartz-keratophyre and albite-diabase, which has been noted by previous workers* among Ordovician igneous rocks in several other British areas.

C. B. T.

(4) Cwm Dywyll Sill.

The close association of this sill with the Tuffs Series III is shown in the field, but the late author remarks in his notes that he had not been able to discover an example of actual contact along the whole length of the strike. It is also clear that at no point has the basic magma completely penetrated the overlying "ashes," but near the grouse-box on Craig Wen a line of weakness in the bedding of the latter has permitted a partial invasion by the sill. Weathered blocks of both rocks are now indiscriminately mixed together, and no arbitrary boundary can be fixed. The final traces are observed on Post Gwyn at its southerly termination, the slope to Blaen Eiarth affording no further evidence.

The rock composing this sheet is deeply weathered and friable for several inches below the crust. Many specimens are structureless and of a pale-grey amorphous

* H. Dewey and J. S. Flett. "On some British Pillow-lavas and the Rocks associated with them." Geol. Mag., Vol. viii, 1911, p. 202 *et seq.* A. H. Cox. "Note on the Igneous Rocks of Ordovician Age." Brit. Assoc. Report, 1913, p. 496.

nature. A segregation of essential minerals is at times visible, the felspars, or their pseudomorphic equivalents, and pyroxenic minerals being grouped in local aggregates. The structure where well shown is ophitic to granular, sometimes slightly porphyritic. The colour of the rock is generally greenish-grey, and felspathic types are apparently largely changed into a pale-yellow felsitic material. The microscope reveals the rock to be a typical Welsh dolerite, and when of coarse grain it affords examples of ophitic structure, but decomposition and, to some extent, dynamic stress have altered its original character.

F e l s p a r. The proportion to pyroxene appears to be about 6 : 2. A number of phenocrysts retain sufficient clearness to enable the species to be determined. The examination under the microscope confirms the conclusion arrived at with regard to the felspars of the other sills of the region, viz., that the same type persists throughout. Mechanical stress has resulted in curved and twisted twin-planes and faulting of individuals. The inclusions are epidote, zoisite, and mica-scales.

P y r o x e n e. The augite is normal, semi-ophitic to ophitic, frequently idiomorphic; pale-brown to pink in colour in transmitted light. It shows well-defined cleavages. Some of the beautifully moulded plates show optical continuity over large areas of the sections.

A m p h i b o l e. An interesting feature of the rock is the presence of brown hornblende, which, however, is not abundant, as out of 22 slices cut only three showed traces of this mineral. It occurs as isolated plates, sometimes showing traces of prism and clinopinacoid, and also as a border to idiomorphic augite. In transmitted light it varies from almost colourless to golden-brown; between crossed-nicols it shows strong absorption, extinguishing at 18°-22°. It is also strongly pleochroic, and the prismatic cleavage of 124° is clearly visible. It alters into serpentine, and on the edges of some of the plates is seen an emerald-green semi-fibrous pleochroic mineral, indicating a change into actinolite or probably smaragdite. While some of the mineral appears undoubtedly of paramorphic origin, the "complementary" hornblende intergrown with the augite may be contemporaneous or perhaps a little younger.

Biotite is represented by a few bent fibrous plates, highly decomposed, showing faint pleochroism.

Accessory minerals. There is but little to record under this heading. Very little magnetite is present; ilmenite in large plates, with its later development into leucoxene, occupies considerable areas, and apatite in its usual form is common.

Secondary minerals. These are practically the same as those of the intrusions previously described. Carbonates in fair quantity are represented by calcite, chalybite, and a little magnesite. Epidote is in places almost as plentiful as in the Cader Berwyn rock, occurring as isolated grains, granular nests, and idiomorphs. Some of the larger individuals exhibit most of the crystallographic development common to the colourless type. A few slides show specimens of highly refractive character, with brilliant interference-colours. Zoisite is occasionally seen in association with epidote in fairly large forms, and the fission parallel to the basal plane is well shown in many instances. The mineral is of tabular habit, well striated, and polarises in low colours. Chlorite and serpentine are both common, at times to the exclusion of other minerals.

Zeolites are represented by analcite and natrolite, the former rare as small pellucid grains, the latter in radial wisps and acicular groups.

The average of 16 tests gave 2·876 specific gravity, the exceptions 2·927 and 3·131 resulting from an excess of epidote and ilmenite respectively.

Dr. Teall* shows a plate of a rock from Clochnant which well exhibits the characteristics of the Cwm Dywyll intrusion. He suggests that the "yellow serpentine may result from olivine," but no definite trace of this latter mineral was found after a careful examination of specimens of the sill.

C. B. T.

(5) Springhill.

This rock, which differs somewhat from the other Berwyn basic intrusions, is exceptional as rising on the strike of the third acid tuff beds or upon the fault cutting them. While essentially of doleritic facies, the presence in part of a definite groundmass might even warrant the term andesitic-dolerite.

The rock is tough, compact, dark-green in colour, and shows little susceptibility to weathering. The exposure in the dry gully in Springhill wood is massive and without fissility, but it has a rough system of platy jointing. Texture and grain are dense, and the dull surface is relieved by the glistening of narrow laths and broader forms of felspar.

The microscope reveals a combination of hemi- and holocrystalline structures, at times even semi-ophitic, but the determination is rendered difficult by the large amount of decomposition-products. Even in fresh specimens the structure is somewhat obscured, but with the greater part of the weakly polarizing constituents incident light distinguishes those of saussuritic nature from the large amount of isotropic material which appears so common in these Welsh rocks. Felspar and pyroxene in close relationship are the principal constituents.

The felspars are rather remarkable as regards size, structure, and habit, and on the whole show comparative

* "British Petrography," Pl. XI, and Q.J.G.S., Vol. xxxvi, p. 279.

immunity to alteration. They are all triclinic, and consist of short stout crystals, tabular plates, and long acicular prisms in radiate and stellate groups. Clear and colourless in hand-specimens, the crystals in thin slices are seen to be free from enclosures or microlites. Twinning when present is usually on the albite law, but examples on the pericline law are also frequent. A simple type of twinning is also in evidence, as well as a single example of the Baveno law. The number of broad plates without twinning is noteworthy. Sections perpendicular to the brachypinacoid give symmetrical extinctions indicating labradorite and andesine with a little oligoclase. Albite may also be present judging from the extinctions which gave a mean of nearly 5° on basal plates from traces of the brachy-pinacoid, and some of the rarer specimens, cut parallel to a line perpendicular to this, approximated 18°.

A marked feature is the tendency to irregular cracking transversely or longitudinal, and entirely distinct from cleavages-traces or plane of composition, although often coinciding with both. Along these lines of fracture decomposition-products have developed, with consequent increase of volume and wedge-like expansion. This takes place at times to such an extent that well-formed phenocrysts have been split apart, and, whilst still retaining a semblance of crystallographic boundaries, now appear as a series of separate plates or laths which often simulate radiate structure.

Pyroxene, which was once a common constituent, is now largely replaced by a dull-brown mineral, structureless and almost opaque. It was the second mineral to crystallize, and is well moulded on the felspar. It is most frequently in granular form, but occasionally the grains show rudely crystalline outlines indicative of former large plates, and such granular clusters are optically continuous over large areas. When the augite assumes the form of long prismatic plates, it is seen that the same disintegrating process has operated, so that the acicular forms observed are essentially parts of plates originally extensive. In ordinary light the mineral is colourless to pale yellow-brown. The former is diopside, and the latter normal augite. A rhombic pyroxene, enstatite or hypersthene, is believed to be present, but the determination was not conclusive.

The colourless sections are at times closely associated with secondary felspar in the matrix, which consists of an admixture of saussurite, kaolin, chlorite, serpentine, and calcite.

The accessory minerals are of slight importance, and comprise ilmenite, zircon, a little sphene, and pyrites. Leucoxene, epidote, and a zeolitic mineral are present as later products.

C. B. T.

(6) Miltir-yr-Gerig.

This isolated triangular patch near Craig-blaen-Rhiwarth, is really a broad dyke rather than a sill, rising from a point South of the locality and cutting across the bedded shales. An offshoot, 15 feet wide, penetrates the grits and slaty beds which are much altered, developing in the former a columnar structure near the contact at the northern end.

Hand-specimens are dull-brown or green, often when compact brownish-yellow and earthy, dull-grey when comparatively unweathered. The femic mineral is dark and lustrous, or pale-brown and sub-metallic. All the rocks are highly calcareous, doubtless owing to the proximity of the overlying Bala Limestone. A patchy appearance, which is not uncommon, is due to free silica occurring as curiously rounded patches of milky quartz. Natrolite occurs in the same manner, and in either radial or massive, some very perfect nests of this mineral of fibrous habit attaining a diameter of 1 cm. Chalcedony and semi-opal also occur in cavities. In some places a doleritic tuff or breccia is suggested, such clastic appearance being accentuated by weathering. In most specimens there is evidence of an old vesicular structure not found in the sills of the district. When most fresh the surface is dark-brown with ophitic traces and a greasy lustre.

A strong susceptibility to weathering is observed in the main body of the rock, and this expresses itself in a banded arrangement visible on eroded faces. Parallel courses of incoherent decomposed material alternate with hard dolerite which breaks with a cuboidal fracture which develops subsequently into spheroidal excafoliation. Later phases of weathering are the formation of a loose sand and finally a gritty clay. This mode of disintegration by atmospheric agencies is not common with Welsh rocks, and resembles more the weathering of the Tertiary basalts of the Western Isles.

The least altered specimens were obtained from the core of an excafoliating nodule (115); there is no reason to presume that the bulk of the mass differed materially from this, yet it is noteworthy that, although enveloped in a crust practically disintegrating into sand, the essential minerals should possess the stability they do.

The dull-black pyroxene seen in hand-specimens may be computed under the microscope to constitute nearly 60 per cent. of the rock. It is present for the most part in large brown plates of normal augite.

Hornblende is only slightly represented as marginal changes, and the quantity present is minute. In association therewith are seen some pale-green fibrous tufts of actinolite.

The felspars are quite subordinate. Generally the augite is moulded on them, but there is evidence in places of simultaneous crystallization of these two constituents. Short prisms are the rule, but long simply twinned individuals occur, and optical tests prove them to be andesine-labradorite or labradorite. Isolated phenocrysts enveloped by later augite show by their constant angles that the more basic mineral is posterior to them. Some fine examples of zoning occur where larger crystals assume a more tabular habit. A few crystals, giving high extinction-angles, suggest the presence of anorthite. Residual felspars are present as groups of microlites. Traces of a black biotite-mica are seen for the first time as small ragged plates showing strong pleochroism.

Accessory minerals consist of apatite, ilmenite, and magnetite, and the secondary minerals comprise epidote, calcite, quartz, chalcedony, leucoxene, chlorite, serpentine, and natrolite in fans.

In addition to the foregoing, the green sand, on fractioning with heavy liquids, yielded the following additional minerals:—Opal, sphene, garnet, limonite, zircon, chalcopyrite, pyrites, rutile, hematite.

The mean specific gravity is 2·724, which is rather low for this type of basic rock.

Altered Tuffs. The origin of some masses of obviously foreign rock, occurring within the doleritic area, and apparently a modification of the complex, appeared for long to be a matter of doubt to the late author, but detailed examination of the dyke and its field-relations with the upper tuff beds III to the South showed that included acid rocks were present. These much altered rocks were referred to by him as "super-silicified tuffs and breccias." Owing to the similarity of the weathering-tints these included masses are difficult to detect, but under the microscope they can be seen to differ.

The greater part consists of a much altered form of fine-grained tuffs masked by secondary minerals. The usual type of fragmentary rock built up of dusty interstitial matter prevails. The large orthoclase phenocrysts of the Peripheral Series are rare, and instead we find aggregates of short triclinic prisms which mostly give the extinction-angles of oligoclase. Original quartz phenocrysts are represented by an uncommon type of granular aggregates. Secondary silica occurs as large areas of milky quartz which, occupying former cavities, show between crossed-nicols a radial habit and highly distorted polarization. Large plates with enclosures exhibit strong strain-shadows. Leucoxene is the only other recognisable constituent. Vein-calcite, probably derived from the overlying Bala limestone, traverses the rock in irregular fashion. The presence of an intimate combination of serpentine and chlorite in large isotropic patches is difficult of explanation unless derived from the basic rock in which it lies, as ferro-magnesian minerals are never prevalent in the tuffs. A simulated flow-structure and a slight tendency to spherulitic structure in the groundmass testify to the altered condition of the rock.

In the same group another peculiar rock resembles a greenish semi-translucent felsite with platy fracture and strong earthy smell. The microscope shows this to be a tuff of intermediate nature, slightly more andesitic than rhyolitic. It consists mostly of a cryptocrystalline groundmass with large areas of serpentinous material. There are included short felspars (oligoclase ?), masses of granular quartz, and some calcite. A little magnetite completes the general features of this obscure pyroclastic rock.

"It may be that the dyke intruded more or less vertically rose "to its position high in the Bala series by piercing the obstructing "tuff beds dipping at 25°, and came to rest near their upper "surface. Not only were the tuffs penetrated, but large blocks "were carried upward and floated off by the basic magma to where "the latter cooled down as an imperfect laccolite. In the case of "the Cwm Dywyll sill, the resistance of the tuff bands against which "it impinged was sufficient to prevent breaking through."—(T. H. C.)

C. B. T.

Summary of Characters of the Basic Rocks.

In reviewing the characters of the basic intrusions of the region, the rocks described in the foregoing pages may be described. with the exception of the Carnedd-y-Ci type, as dolerites in their original state. Variations naturally occur, such as the prominence of the basaltic type in parts of the Llyn-Llyn-Caws sill, and the remarkable development of stellate grouping of the felspar phenocrysts at Hendre, while in more than one locality for all the sills there are portions which show a reversion to an andesitic type.

In only a few instances does brown hornblende, whose primary origin is doubtful, occur. Olivine, always closely looked for, is never actually indicated, and if at times an excess of magnetite dust or a profusion of yellow serpentine might tempt one to assume its former presence as a rock-constituent, no idiomorphic clue is now visible. The diabasic condition is always seen, and beyond that a bodily conversion into massive serpentine, as at Pen-y-Bont, is not rare.

A comparison with the dolerites of Carnarvonshire, described by Harker,* brings out the salient features common to the basic rocks of both areas, and it will be seen that there are many points of similarity. In the Lleyn rocks the general characteristics of the plagioclases, classed in the andesine-labradorite series, approximate nearly to those of the Berwyns, with some important exceptions. A striking difference is the more or less albitized condition of the felspars of certain of the Berwyn dolerites. No evidence of albitization has hitherto been recorded from the basic rocks of North Wales,† but it is possible that future investigation may show that this feature exists to a greater extent than has

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* "The Bala Volcanic Series of Carnarvonshire," pp. 75-86.

† Dr. H. H. Thomas's note on this point in "The Summary of Progress of the Geological Survey," 1913, appears to be the first record.

been suspected. With regard to the monoclinic pyroxenes, although the diallagic condition occurs more frequently in the Berwyn sills, both series may be fairly covered by a common description. While the rhombic pyroxenes appear to be absent from the diabases of Carnarvonshire, there is reason to believe that they have played a not insignificant rôle as a constituent of many of the intrusions of the Berwyn Hills. The brown hornblende patches, noted in the Carnarvonshire rocks by Harker,* are considered to be original, but in the few instances in which this amphibole occurs in the Berwyn intrusions there is always an element of doubt as to the original nature of the mineral.

On the whole, there is a strong parallelism as regards the structure and general mineralogical composition of the rocks of both regions which seems to warrant the conclusion of derivation from a common magma.

C. B. T.

VI. The Age of the Igneous Rocks.†

The sequence of events in the Berwyn region presents, with regard to the igneous rocks, many features in common with those of similar volcanic districts of Wales. As it has now been established that the regional Peripheral Series at least is contemporaneous with formations of Bala age, it is necessary to refer to the history of causal Bala vulcanicity for explanation of this display of volcanic activity so far removed from the area of its maximum development in Carnarvonshire.

"With Harker's exposition‡ I have always been in full agreement, and it seems to me to afford an explanation of the extension from the region with which he dealt to the Berwyn area." (T. H. C.)

* Op. cit., p. 83.

† This and the following section are based on the notes of Mr. Cope.

‡ "The Bala Volcanic Series," p. 112 *et seq.*

The Berwyns, with the other great folds of Wales, were primarily subjected to, and their rocks largely cleaved by, pressure from the North-west, i.e., along lines of "Caledonian" folding, resulting in an ellipsoidal dome running approximately in direction North-east/South-west. Such folding finds a close parallelism in Carnarvonshire, a movement of pressure from an opposite quarter acting along a South-east/North-west line, with the axes of disturbance also approximately North-east/South-west. In both cases the results were similar, the crushing back of a South-east division against an area of resistance. In the one case the rigidity of the Archaean ridge was opposed to a steady thrust, probably deep-seated; in the other there was the pressure of a perhaps more superficial creep against the piled-up mass of the Berwyn anticline, of which the folding process was not necessarily extinct. For another parallel we find that the strike in both districts describes a flat curve, with the concavity facing South-east, but in Carnarvonshire the disturbance resulted in but few faults and intense local plication and cleavage. In the Berwyns the effect has been one partaking more of the nature of torsion-folding, with consequent breaking up of the country, for the innumerable minor faults, as yet unmapped, the vertical dip in isolated blocks, the general chaotic arrangement of dip-directions, and the broken strike of cleavage-directions, are sufficient evidence of a shattered territory. For further proof we must turn to the long strip of reversed beds bounding the area on the South, an inversion shared later by Silurian formations.

While the principal axes of folding generally agree in both districts, they lie parallel, and not in prolongation, but in both cases it must be assumed that the waves of the same lateral stress affected the respective districts, permitting that accumulation of potential energy which was to be manifested later in the volcanic activity common to both areas.

The delimitations of the various volcanic groups of Bala age in Carnarvonshire are now sufficiently well established on general lines, despite the obvious overlapping which occurs in many instances.

Ramsay considered the "Bala Limestone" as the equivalent of the Upper Calcareous Marine "Ashes" of Snowdon, but the volcanic rocks of the Berwyns, lower than that horizon, have no petrographical resemblance, and such water-deposited rocks are apparently not otherwise represented in the area. On the other hand, the Peripheral Tuffs come into place in close relationship with the Caradocian series of the Upper Bala, and may be considered as belonging in part to the southern end of the Conway slope, representative of a late period of activity in Snowdon volcanic times, having affinities with the Caradocian beds of this locality. This being so, the lower rhyolitic lavas of Llangynnog may be referred in point of age to an earlier group of the main or lower Snowdonian lavas, probably from their position that of the Capel Curig-Dolwyddellan group.

True andesites of Bala age are not frequent in Wales; at least there are as yet few records. The eastern Berwyn volcanic platform of andesitic facies is of considerable interest, as, so far as can be ascertained by a careful measurement, it seems to represent the latest phase of vulcanicity on, or probably above, the position of the Bala Limestone, which is here hidden by the overfolding of the calciferous sandstone series of Llanfyllin. It is possible that in relation to period there may be a correspondence between these rocks and those of similar age described by Messrs. Kilroe and McHenry* in the South of Ireland. In any case, their easterly prolongation beneath the limestone will doubtless be found to be continuous with the same formation in the Breidden Hills, the Bala beds, and the associated andesitic lavas and tuffs of Moel-y-Golfa and Middletown.

* Q.J.G.S., Vol. lvii, 1901, pp. 479-489.

With respect to the lowest group of all, the lavas and tuffs of the Craig-y-Glyn series, near Llanrhaidr-yn-Mochnant, it has been generally accepted that the black shales contemporaneous with these volcanic rocks are of Llandeilo age. The classification of the latter sediments does not yet permit us to allocate the igneous rocks exactly to their place in the sequence, and more palaeontological work and a revision of the boundaries of this small area appear necessary. On the North-east flank of Arenig, as is shown by Fearnsides,*, rocks of Llandeilo age have not been found, yet the Llanrhaidr volcanics have many petrographical affinities with those of the former region, which seems to warrant us bringing them into order as the product of eruptive activity in the Upper Arenig period. C. B. T.

VII. Probable Vents.

The country is admittedly isolated, and the pyroclastic beds dipping North and West under the Silurian syncline thin out uniformly in the fault-broken region South of the Bala thrust-plane, so that there seems to be little likelihood of continuity with the Carnarvonshire volcanic group. Even so, there is strong evidence that active vents were in existence near the major axis of folding in late Bala times.

Ramsay held the opinion that one centre of eruption had lain in the neighbourhood of Llandrillo, but he advanced no reason for the assumption, nor any hypothesis to account for the genesis of the igneous rocks of the region. Sir A. Geikie† suggested that "the chief focus of eruption lay rather to the West, perhaps under the trough of Upper Silurian strata somewhere in the neighbourhood of Llanderfel. There was probably another in the Hirnant district."

* "The Geology of Arenig Fawr and Moel Llyfnant," Q.J.G.S., Vol. lxi, p. 640.

† "Ancient Volcanoes of Britain," Vol. i, pp. 176, 186, 208, 218.

Between the period of gentle folding which closed the Tremadocian Series of the Upper Cambrian and the great Caledonian folding which developed with the oncoming of the Ordovician, this district doubtless lay submerged beneath the sea. The volcanic outbursts, the culmination of the stress, gave rise to vents essentially submarine. Among the evidence which may be adduced for this is the prevalence of thin mud-bands near the base of the formations, both in the acid and intermediate series. It is probable that the water was shallow, but while it is a question whether the detritus accumulated more rapidly than the floor sank, it is at least possible to say that the lowest Llandeilian series of Llanarmon were of sub-aqueous origin.

In the andesitic country in the East of the region sufficient evidence has been described to indicate a possible vent in the Glascoed porphyrite mass.

There seems to be no reason for presuming that a centre of activity existed in the Hirnant district, and the mass of repeated bands of "tuffs" has been shown to be composed in reality of intrusive rocks of an unusual type.

At Llangynnog, as described, we find what may be a link with the spherulitic lavas of perhaps late Arenig age. Elsewhere in the Peripheral Tuff series it is found that in band III all the coarser material and the heavier fragments lie East of the Glyn valley, e.g., at Cwm Clwyd, the Craig, and the Springs. In band II the coarsest accumulations in breccia-form lie in widely separated localities to the West, notably at Pen-llyn-gloge, near Pont Rhyd Wilym, etc., obviously in relation to vents in their vicinity. On analysis of the field-evidence we may be justified in assuming a small group of vents active intermittently over a long period, resulting in the accumulation of volcanic beds of considerable area but of no great depth.

As regards the intrusive sills, these are simple in character, and are not complicated by cross-dykes petrologically differing from themselves. In their relation to the acid rocks they may be regarded as the basic residue of a mass in which the acid bulk had already been differentiated. Taking advantage of the continuing earth-wave, the magma became intruded for the most part along bedding-planes at some later period of the uplift, as these intrusive rocks do not occur on horizons higher than the volcanics. The sills are to be studied as being in close association with the lavas and tuffs, the final episode of the volcanic history of this self-contained area occurring in late Bala times.

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VIII. Summary and Conclusions.

The area described includes portions of the counties of Denbigh, Merioneth, and Montgomery, some 150 square miles in extent. The sedimentary formations present range in age from Llandeilo to Upper Llandovery and Tarannon, and have been subjected to cross-folding at two epochs widely separated, giving rise to domal structure.

The igneous rocks associated chiefly with the Ordovician sediments occur at various horizons, and comprise acid and intermediate lava-flows and intrusive sheets of intermediate and basic composition, some of which present unusual types hitherto not recorded from North Wales. The massive volcanic rocks, which are distributed over the southern portion of the region, are spherulitic rhyolites, hornblende-porphyrites, hornblende, augite, and enstatite-andesites, associated with rhyolitic and andesitic tuffs, breccias, and agglomerates, and their probable sources of origin are indicated by vents in several localities. The earliest eruptions commenced in the Llandeilo, or perhaps Upper Arenig, period, and continued at intervals throughout the Bala period. The early acid extrusions may be correlated with the volcanic rocks of the Arenig district, and the later Bala flows correspond with the Snowdonian lavas of the Capel Curig-Dolwyddellan group. The succeeding andesitic lavas are doubtless related in origin and time to those of the Breidden Hills. The intermediate and basic intrusions are considered to be of later date than the contemporaneous lavas, and, with one exception, they occur on the northern and western borders of the area described. They comprise keratophyres, analcite and albite dolerites.

A remarkable member of the intermediate group, rich in soda, which corresponds with no description yet published, has been provisionally designated "Hirnantite."

In conclusion, while it is impossible for me to ascertain to what extent the late Mr. Cope was indebted to individuals for facilities and information during the course of his investigations, special acknowledgment is clearly due to the late Mr. Joseph Lomas, F.G.S., and Mr. C. C. Moore, F.I.C., for their assistance and companionship in the field on many occasions, as well to the latter gentleman for the chemical analyses which he supplied to the late author.

Personally, I wish to express my own indebtedness to Dr. H. H. Thomas (Sec. Geol. Soc.) for help in the determination of some of the rock-types described, and to Mr. H. W. Greenwood for the chemical analyses which he has kindly made for me. C. B. T.

EXPLANATION OF PLATES.

Plate I.

Fig. 1. Rhyolitic Tuff, quarry Cae-deicws, Glyn Ceiriog (No. 205). Showing phenocrysts of quartz, orthoclase, and plagioclase in a siliceous crypto-crystalline base.

Fig. 2. Spherulitic Rhyolite, summit Craig Rhiwarth, Llangynnog (No. 111A). Showing large spherulites and orthoclase phenocrysts in a matrix of allotriomorphic quartz and turbid felspar.

Fig. 3. Hornblende-porphyrite, Bruce Quarry, Glascoed, near Llansilin (No. 110). Phenocrysts of andesine and hornblende in a groundmass of oligoclase microlites, chlorite, calcite, iron-ore.

Fig. 4. Hornblende-andesite, Moelydd, north of Llanyblodwel (No. 146). Phenocrysts of oligoclase-andesine felspar in a glassy groundmass with hyalopilitic structure.

Fig. 5. Keratophyre, quarry Coed-y-glyn, Glyn Ceiriog (No. 158). Microlites of acid oligoclase with flow-structure, chlorite, granular sphene, calcite, &c.

(All polarized light × 30.)

Plate II.

Fig. 1. "Hirnantite," Craig-ddu, Hirnant (No. 178). Showing oligoclase-andesine plagioclase in radial arrangement with interstitial chlorite.

Fig. 2. Variolite, contact of "Hirnantite" with slate near adit-level, Craig-ddu, Hirnant (No. 108A).

Fig. 3. Analcite-dolerite, Hendre Quarry, Pen-y-bont, Llansaintffraid D.C. (No. 154). Showing phenocrysts of andesine-labradorite felspar, with ophitic structure of augite; serpentine.

Fig. 4. Quartz-keratophyre, south end of summit of Carnedd-y-Ci (No. 117). Albite phenocrysts in a matrix of oligoclase-albite microlites, allotriomorphic quartz and interstitial chlorite.

Fig. 5. Albite-diabase, summit of Carnedd-y-ci, facing Foel-fawr (No. 187). Albite phenocrysts, granular augite, iron-ores, and calcite.

(All polarized light × 30.)

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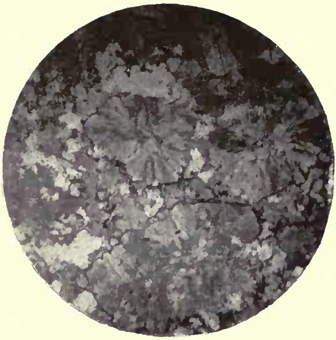

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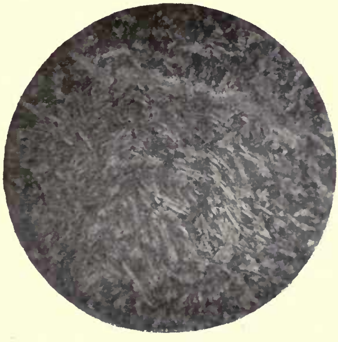

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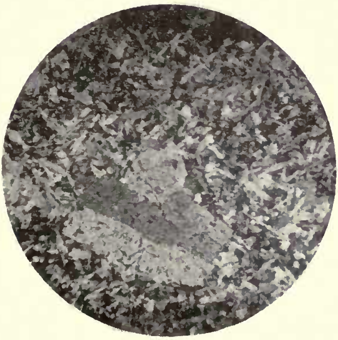

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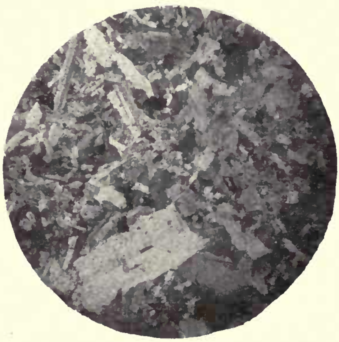

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